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JAN 81 G P BOUCEK, D A PO-CHEDLEY, B L BERSON DOT-FA/9WA-4268

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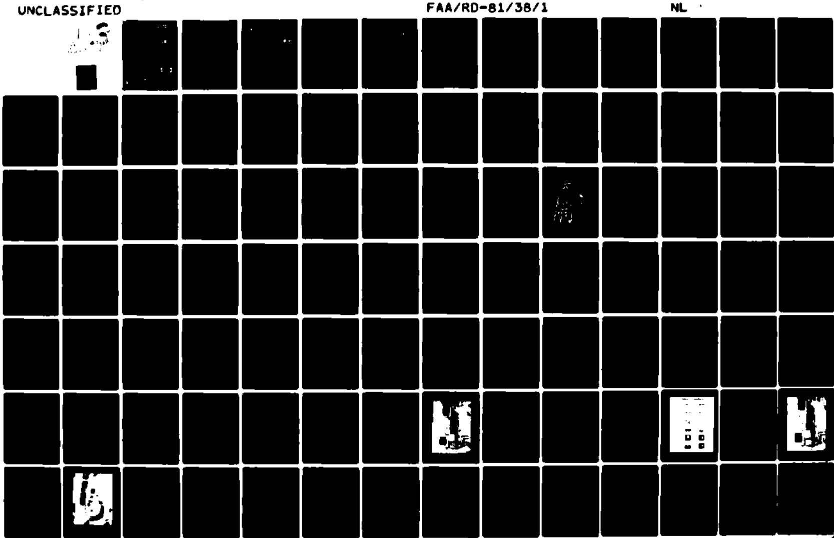

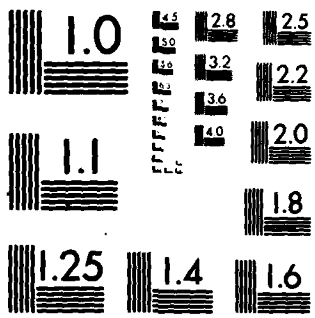

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Aircraft Alerting Systems Standardization Study

Volume I

Candidate System Validation and Time-Critical Display Evaluation

12 LEVEL III

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January 1981

Final Report

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NOTICE

NOTICE

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15. Supplementary Notes

16. Abstract This report is one of a series of documented studies directed to the improvement and standardization of aircraft alerting systems. The purpose of the study was to develop and validate, through simulation, functional design criteria that can be used in designing effective aircraft alerting systems. The major objectives of this phase of the study were to:

- Resolve system component questions
- Validate the two candidate system concepts by comparison to a representative baseline system, for both the pilot and flight engineer stations
- Evaluate presentation media and display formats for time-critical warnings
- Develop guidelines for the design of alerting systems.

The system component questions were resolved in a series of experiments and the results were integrated into two system concepts for validation. In the validation tests, line-qualified pilots exercised the three alerting systems in a full-mission, fixed-base simulator. In all areas of measurement pilot performance was as good or better with the two candidate system designs than with the conventional, baseline system. The results indicate that a flight engineer station should contain the visual display components offered by the candidate system concepts. Voice was the recommended medium of presentation when rapid response is required. The time-critical display tests showed that fastest pilot response performance was obtained when graphic guidance alerts were placed in the pilot's primary field of view. The functional design criteria that were developed are contained in "Aircraft Alerting System Design Guidelines," Report Number DOT/FAA/RD-81/38/II.

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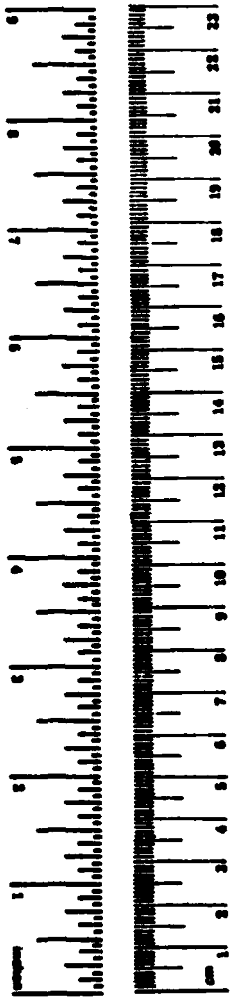
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

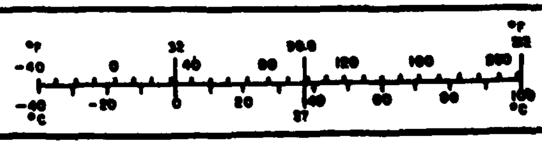
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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PREFACE

This report is the result of several years of research sponsored by the FAA directed toward the improvement and standardization of aircraft alerting systems. This present study was conducted as a joint effort by the three major U.S.A. manufacturers of commercial transport aircraft: Boeing, Lockheed, and McDonnell Douglas. The primary purpose of this volume is to report the system validation and the time-critical presentation media tests. The objectives of these tests were to validate the system design concepts identified in the first phase of the study and to evaluate presentation methods for alerts which announce situations or conditions which require an extremely rapid solution.

The authors want to express appreciation to the many pilots from the three aircraft companies and from Continental, Western, American, United, TWA, Eastern, Northwest Orient, and SAS Airlines who participated in this project. Also, the experience and guidance of Wayne Smith, the Boeing Program Manager, was of great value, as were the contributions of Dr. Richard Gabriel, Don Stanley, and Art Torosian of Douglas, and Ralph Cokeley, Les Susser and Chuck Mercer of Lockheed. The efforts of Russell White in the preparation of the simulator and his help in conducting the tests were also appreciated. The contract sponsor is the Federal Aviation Administration, and technical guidance was provided by John Hendrickson, ARD 340, the contract monitor.

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LIST OF ABBREVIATIONS

ADI	Attitude Director Indicator
ALPA	Airline Pilots Association
ANOVA	Analysis of Variance
ARP	Aerospace Recommended Practice
ATC	Air Traffic Control
CAWS	Caution and Warning System
χ^2	Chi Squared
CPU	Central Processor Unit
CRT	Cathode Ray Tube
dB	Decibel
DETAC	Digital Equipment Technology and Analysis Center
df	Degrees of Freedom
EADI	Electronic Attitude Director Indicator
ELF	Electroluminescent Film
ft-L	Foot-Lambert
HUD	Head-Up-Display
Hz	Hertz
ILS	Instrument Landing System
LAX	Los Angeles International Airport
LCD	Liquid Crystal Display
LED	Light Emitting Diode
mL	Millilambert
msec	Millisecond
NASA	National Aeronautical and Space Administration
PAWS	Phase Adaptive Warning System
sin	Sine of an Angle
SMOLD	Switch Monitor and Light Driver
S/N	Signal to Noise Ratio
VFR	Visual Flight Rules

1.0 INTRODUCTION

This contract is the fourth in a series directed toward the improvement and standardization of aircraft alerting systems. The effort began in 1973 with a study of concepts for an independent altitude monitor, and has evolved into the study of advanced cockpit alerting system concepts and design criteria. With each effort it became increasingly obvious that the design of aircraft alerting systems has not followed a systematic approach, but rather has been detailed by the requirements of individual systems. As requirements for new alerts were identified these additional alerting elements were placed in the flight deck with little regard to integrating them with other alerting elements. While a good data base of philosophies, pilot-response characteristics, and design guidelines were obtained, increasing evidence of alert proliferation and inconsistent application of alerting concepts were found (Cooper, 1977; and Veitengruber, Boucek, and Smith, 1977). Those studies clearly indicated that the aircraft manufacturing industry needs a set of guidelines for designing aircraft alerting systems for the next generation of commercial transports. Those studies also provided general recommendations for standardizing alerting functions and methods. However, those studies also assessed the adequacy of the existing alert system data base and recommended additional comparative testing of not only alerting system elements but also full alerting system concepts be used to refine and validate the design guidelines. It was recognized that any recommendations must be based on data and reflect a consensus of manufacturers, certificating organization, operators and pilots to be of value.

The present contract was awarded to obtain empirical pilot performance data to refine and validate the preliminary alerting system concepts and criteria. The contract was performed in three phases. The first phase consisted of an evaluation of individual alerting system components (e.g., master visual alert, voice information display), and resulted in the definition of candidate alerting concepts. The assumptions upon which the first study was based can be seen in Table 1.0-1. The candidate alerting concepts were developed to cover the alerting requirements for a three level alerting system (warning, caution and advisory). Table 1.0-2 defines these levels and illustrates the alerting system components required to mechanize them. The Phase 1 effort is

Table 1.0-1. System Assumptions for Aircraft Alerting Systems Standardization Study

- No nonverbal aural alerting system with different alerts for each condition or alert (large number of aurals)
- No incandescent light or fixed-legend display for primary central display unit
- Secondary subsystem indicators will be reflected on the central display
- Dual-channel auditory and visual presentation for some if not all alerts
- Primary visual system will be programmable; subsystem indication may be fixed
- Auditory system voice components
- Auditory system tone components
- System direction toward an electronic flight deck
- Form of prioritization implemented
- Form of automated inhibition needed; e.g., don't use voice when it might conflict with ATC communications
- Computing capability (smart system) to handle prioritization, inhibit, and other system logic
- Design for the quiet, dark cockpit
- May want some alerts to bypass computer for backup in a failure mode
- Central display primarily alphanumeric but may have graphic or symbolic capabilities
- Automatic indication clearing when fault or alert condition no longer exists
- Best available speech-generation equipment
- System based on four condition levels; i.e., ARP450D:
  - Warning
  - Caution
  - Advisory
  - Information
- Central display with color capability
- Capability of readily accommodating all present and future alerting functions; e.g., BCAS, GPWS
- Basic functions to include—
  - Alert (attention getting)
  - Inform (identify the problem)
  - Guide crew action
  - Provide feedback
- Includes interactive capabilities

documented in Boucek, Erickson, Berson, Hanson, Leffler, and Po-Chedley (1980). The second phase consisted of developing a detailed test plan for evaluating the candidate concepts in a full-mission simulation. In the third phase, line-qualified pilots exercised the resulting alerting systems in a simulator, and a set of design guidelines directed at the improvement and standardization of advanced aircraft alerting systems was developed. The intent of these guidelines is not to define a single alerting system design that each manufacturer must use, but rather to provide functional design criteria that can be used to develop effective alerting systems, and to promote standardization within the industry. These guidelines, provided in

Table 1.0-2. Alerting System Categorization

Condition	Criteria	Alert system characteristics		
		Visual	Aural	Tactile
Warning	Emergency operational or aircraft system conditions that require immediate corrective or compensatory crew action	Master visual (red) plus centrally located alphanumeric readout (red)	Unique attention-getting warning sound plus voice*	Stick shaker (if required)
Caution	Abnormal operational or aircraft system conditions that require immediate crew awareness and require prompt corrective or compensatory crew action	Master visual (amber) plus centrally located alphanumeric readout (amber)	Unique attention-getting caution sound plus voice*	None
Advisory	Operational or aircraft system conditions that require crew awareness and may require crew action	Centrally located alphanumeric readout (unique color)	Unique attention-getting advisory sound	None
Information	Operational or aircraft system conditions that require cockpit indications, but not necessarily as part of the integrated warning system	Discrete indication (green and white)	None	None

*Voice is pilot selectable.

Volume II of this report (Berson, Po-Chedley, Boucek, Hanson, Leffler, and Wasson 1981), have been substantiated by experimental data and do reflect views of commercial transport aircraft manufacturers, certification authorities, airline operators and pilots.

The objectives of these guidelines are to provide standardization in alerting system design and methods to reduce the overall number of discrete visual and aural alerts in the next generation of commercial jet transports. By accomplishing these objectives the demands on crew information processing and memory capabilities should be reduced. The time required to detect and assess failure conditions should be minimized, as well as the time to initiate the appropriate corrective actions. There should be fewer distractions from the crew tasks of aircraft control and communications. By standardizing the

alerting system, all airframe manufacturers, airline operators and pilots will share the benefits of a commonality of design. The standardized system should also provide for alerting system growth and improvement in a form that does not necessitate additional discrete annunciators.

The present study was conducted as a joint effort between Boeing, McDonnell Douglas and Lockheed Aircraft Companies, and was sponsored by the Federal Aviation Administration.

This report contains two volumes. Volume 1 describes the:

- Supplemental tests that were conducted to select between alternative alerting system elements.

- Simulation tests that were conducted on the candidate alerting concepts, identified in Phase 1, to validate these concepts by comparison to a conventional "baseline" system, (i.e., representative of systems currently in use). Validation tests were conducted for pilot and flight engineer stations.

- Simulation tests that evaluated alternative concepts for providing time-critical warning information to the flight.

The second volume contains the alerting system design guidelines.

1.1 REPORT ORGANIZATION

Section 2 of this report contains an executive summary of the major activities and findings of the Phase 3 testing effort. The supplemental studies conducted to select between alternative concepts for implementing the alerting functions, and the results of these studies are described in Section 3. Section 4 describes the system validation tests, including the tests conducted at the pilot and flight engineers stations, and the time-critical tests. Discussions of the major findings and the conclusions drawn from this data are presented in Section 5, and Section 6 describes additional study efforts that should be undertaken to incorporate aircraft or operational specific

considerations into the alerting system design, and then to implement the design in hardware for a flight evaluation phase.

The Appendices at the end of this report describe the facilities used at Boeing and Douglas to perform the system validation and supplemental tests and contain example illustrations of the interactive capabilities of the visual information display. Also included are the questionnaires that were used to obtain pilot input for incorporation into the guidelines.

2.0 EXECUTIVE SUMMARY

2.1 PROGRAM BACKGROUND

The present contract, performed in three phases, was directed toward the improvement and standardization of aircraft alerting systems. In Phase 1 the primary functions of an advanced alerting system were defined, and alternative concepts for implementing those functions were evaluated through simulation. The final effort of Phase 1 was to develop candidate alerting concepts. These concepts were to be implemented by combining the individual functional elements, evaluated in Phase 1, into systems that best satisfied the requirements for crew alerting. The systems were composed of elements forming four major system components, master visual alerts, master aural alerts, visual information display, and the voice information display. Two systems were defined. The two candidate designs, presented in Tables 2.1-1 through 2.1-4, are quite similar, differing only in their implementation of the voice information display. System A provides automatic voice messages for all warnings, whereas, System B provides voice messages for warnings and cautions but which are annunciated only when selected by the pilot. To provide a baseline for validating the advanced systems, a conventional system, representative of alerting schemes currently in use, was developed. The characteristics of the conventional system are presented in Table 2.1-5.

In the process of identifying the characteristics of the candidate systems a number of questions arose concerning alternative methods for accomplishing alerting system functions. Alternative designs were identified for accomplishing the master visual alert, for performing the alerting and informing functions for advisories, and for annunciating multiple-alerting situations. It was also recognized that some conditions or situations may require crew action to be accomplished in an extremely short period of time. These situations were termed "time-critical", and alternative presentation media and formats were developed for evaluation in Phase 3.

Table 2.1-1. Visual Master Alert

Variable	Concept A	Concept B
Number	Two	*
Location	Near 15-deg cones	*
Flash	No	*
Brightness	15 to 150 fL	*
Size	1 deg	*
Cancellation logic	Manual and automatic	*
Duty cycle	N/A	*
Color	Red, yellow	*

Table 2.1-2. Aural Master Alert

Variable	Concept A	Concept B
Number	Three	*
Signal-to-noise ratio	5 to 10 dB	*
Cancellation	Manual and automatic	*
Stereo type alerts	No	*
Duty cycle	N/A	*
Spectral character	In guidelines	*
Location	90 deg	*
Masking	Controlled via design	*

*Variable is identical for both concepts

Table 2.1-3. Visual Information Display

Variable	Concept A	Concept B
Location	Central display	*
Format	Priority and chronological	*
Overflow	Paging	*
Store-recall	Yes, except for warnings	*
Brightness	15 to 150 fL	*
Cues and aids	Box, arrow, etc.	*
Content	Short phrase (syntax)	*
Character size	14 min	*
Character spacing	7 min	*
Legibility	In literature	*

Table 2.1-4. Voice Information Display

Variable	Concept A	Concept B
Type	Warnings	Warnings and caution elective
Format	Phrase	*
Model (M/F)	Female	*
Inflection	Monotone	*
Masking	Controlled by design	*
Repetition	Yes	*
Cancellation	Manual	Manual switch
Content	Status	*
Signal-to-noise ratio	5 to 10 dB	*
Multiple alerts	In sequence with repetition	No
Store-recall	No	Yes
Spectral character	Guidelines	*
Location	90 deg	*

*Variable is identical for both concepts.

Table 2.1-5. Baseline Configuration

	Yes/no	Location	Color/tone	Flash
Master warning	Yes	Glareshield	Red/no	No
Single master				
Split legend				
Master caution	Yes	Glareshield	Amber	No
Central display				
Fixed legend	Yes	Central panel	Red, amber, blue	Yes, without master
Alphanumeric	Yes		Red, amber, blue	No, with master
Monochrome	No			
Distributed annunciators	Yes	N/A	Red, amber, blue	No

ADDITIONAL FEATURES:

Dedicated tones:	Electronic-mechanical mix; also includes SELCAL, CREW CALL; cancellable, dedicated cancel switches
Voice message:	GROUND PROXIMITY, cockpit speaker environment
Inhibits:	No
Cancel/recall:	Yes; can cancel masters and central display; cannot cancel distributed annunciators

In Phase 2 detailed test plans were developed for:

- Resolving the system component questions.
- Validating the two candidate system concepts by comparison to a representative baseline system, for both the pilot and flight engineer stations.
- Evaluating presentation media and display formats for time-critical warnings.

The major objectives of Phase 3 were to perform the evaluations discussed above, to analyze the resulting data with all other available data, and to develop a set of design guidelines for alerting systems. The intent of the guidelines is not to define a single design that all airframe manufacturers must use, but rather to identify functional design criteria that can be used to develop effective alerting systems, and to promote standardization within the industry. This volume describes the Phase 3 testing effort, and Volume 2 contains the design guidelines.

2.2 SUPPLEMENTAL TESTS

In developing the candidate system concepts in Phase 1, a number of questions arose concerning the design of various alerting system elements. Additional tests were designed to obtain resolution to those questions. These supplemental tests were conducted at McDonnell Douglas, Long Beach, California and were completed prior to the major Phase 3, simulation testing, which was conducted by Boeing Commercial Airplane Company, Seattle, Washington. The areas that required resolution prior to conducting the Phase 3 testing are summarized in the following paragraphs and are described in detail in Section 4. The supplemental tests were divided into issues that addressed system component design, and alerting system logic. The vast majority of data used to resolve these issues were obtained from questionnaire surveys of 25 current line-qualified pilots, following demonstrations of alternative designs in the Douglas simulator.

2.2.1 SYSTEM COMPONENT TESTS

2.2.1.1 Design of the Master Visual Alert - This test involved evaluating the relative advantages and disadvantages of separate master visual lights for warnings and cautions versus a single split-legend indicator labeled WARNING on top and CAUTION on the bottom. The results of this test indicated that the pilots were more concerned with the size and location of the master visual alerts than they were with whether they were separate or combined.

2.2.1.2 Requirement for a Master Visual Advisory Alert - This test addressed whether a master advisory alert should be provided in alerting systems. The results of the test indicated that a master visual alert was preferred in conjunction with the annunciation of advisory alerts via a master aural alert (single stroke chime), and presenting the alert on a visual information display.

2.2.1.3 Interactive Functions - This evaluation addressed the mechanisms to enable the crew to interact with the alerting system. One question was the desirability of providing the crew with the capability to store alerts (i.e., remove them from the visual display and store them in memory), and to recall them when desired. Total store/recall (all alerts at one time) and selective store/recall (one at a time) capabilities were investigated. The study results indicated that a combination of total and selective store/recall should be provided.

A second issue was that of providing automatic checklist/procedural information to aid the crew in responding to emergency situations. The vast majority of pilots surveyed (23 out of 25) indicated that this capability should be included in conjunction with aircraft alerting systems.

The pilots were also questioned about the desirability of activating/cancelling aural alerts and messages. The results showed a clear preference for manual cancellation.

2.2.1.4 Verbal Versus Sound Master Alerts - This test was a subjective comparison of using tones or verbal alerts (presenting the word "WARNING",

"CAUTION", or "ADVISORY") as the aural attention-getting mechanism. Slightly more than 50 percent of the pilots interviewed favored the verbal alerts over the discrete sounds. However, since the preference was not statistically significant and there is a greater probability of the verbal alerts interfering with other flight deck communications (e.g., ATC, crew conversations), tones were selected for implementation in the candidate systems for the Phase 3 evaluation.

2.2.2 SYSTEM LOGIC TESTS

2.2.2.1 Prioritization - This test addressed the issue of prioritizing alerts within the three alerting categories (i.e., warning, caution, and advisory) on the visual information display. Optimally, the most important message would always be located at the top of the display, with lower priority alerts below. The results of this survey indicated that while alert prioritization would facilitate crew performance, there was very little agreement on how prioritization should be accomplished.

2.2.2.2 Inhibit Logic - The issue of inhibiting low level alerts during high workload flight phases was investigated. As with prioritization, most pilots indicated that inhibit logic should be incorporated in the alerting system, however little agreement was obtained on what components to inhibit, or when to do so.

2.2.2.3 Visual Message Syntax - The objective of this study was to survey the major aircraft manufacturers to identify the most prevalant alert format. The results of this survey indicated that while no standard format existed, most alerts were presented with the nature of the problem preceeding the location of the problem. The majority of the 25 pilots (80%) also preferred the format which had the general heading, followed by the specific subsystem/location, and the nature of the problem (e.g., ENGINE NUMBER 1 FIRE). However, they stated that a standard syntax may not be appropriate for all alerts, and that while a standard message syntax is desirable, it should be subordinate to a clear statement of the problem.

2.2.2.4 Multiple Verbal Alerts - This test investigated the sequencing of multiple verbal alerts. The alternatives investigated included: (1) Prioritizing the alert messages and annunciating the highest priority alert; (2) Annunciate the highest priority alert for a fixed number of repetitions, then cancel it, and present the next highest message, and so on; and (3) Annunciate the message "MULTIPLE ALERTS" to direct the crews' attention to the visual information display for the specific fault messages. The pilots showed a preference for the annunciation of the message "MULTIPLE ALERTS".

The results obtained via these supplemental tests were incorporated into the Phase 3 validation tests described in the following paragraphs.

2.3 SYSTEM VALIDATION TESTS

The two candidate advanced systems and the conventional alerting system, defined in Phase 1, were implemented in the Visual Flight Simulation Facility at Boeing. Fourteen line-qualified pilots, with an average of 13,600 hours flight experience, participated in the tests. Each flew eighteen test flights of 31 minutes in length and responded to 162 alerts of various urgency levels. Six of the flights were designed validating the advanced systems. Half the pilots flew System A while the other half flew System B. All pilots flew two trials with the conventional system.

To simulate a flight deck environment and work pattern, a realistic aircraft model was used for the basic flying task. In addition, the pilots were required to fly a prescribed flight plan (takeoff, climb, cruise, descent and land), respond to ATC directives, locate and report targets in the external visual scene, and respond to alerts.

In the Flight Engineer tests, conducted simultaneously with the pilot tests, the test subjects were provided a workload to simulate worst-case or near worst-case conditions. The Flight Engineers' tasks included reading instruments, logging problems or faults and their time of occurrence, and locating targets in the external visual scene. Each pilot flew four Flight Engineer trials, two with a conventional system, and two with an advanced system. The results of the Pilot and Flight Engineer validation tests are described in detail in Section 5, and are summarized below:

2.3.1 PILOT STATION TESTS

Using the advanced alerting systems, pilot performance was as good as or better than that obtained with the conventional alerting system, no matter what performance measure was used. Pilot response and detection times were significantly shorter, and fewer alerts were missed with Systems A and B, than with the conventional system.

The pilots' reactions to the candidate advanced alerting concepts were very positive. They stated an overall preference for the advanced systems in comparison to the conventional system. They said that the advanced systems were easier to use and were more effective than the conventional. The master aural sounds were rated very high with respect to both attention-getting quality and total number (3). The pilots singled out the centralized location for visual information display, the unique colors and sounds for each urgency level, the use of voice, and the volume of the aural components as features which they especially liked. The only feature that was objected to by several pilots was that the master aural caution alert used sounded too urgent. In the final analysis, both candidate systems concepts were validated, and a combination of the features of the two systems was used in formulating the design guidelines.

2.3.2 FLIGHT ENGINEER STATION TESTS

The results of these tests validated the candidate system design at the Flight Engineer Station. Shorter response times and fewer missed alerts were obtained with the advanced system in comparison to the conventional system. Pilot opinion data also indicated a strong preference for the advanced system.

2.4 TIME-CRITICAL WARNING TESTS

Each pilot flew twelve flights to evaluate time-critical alerts. Those trials were conducted to evaluate alternative presentation media and display formats. The time-critical tests were identical to the system validation tests except only warning alerts (time-critical and non-time-critical) were presented. Eight alerts were presented in each test flight. The variables investigated were:

- Display Location - in the pilots' primary or secondary field of view
- Presentation Format - alphanumeric, graphic, or both
- Message Content - status or guidance
- Accompanying Voice Alert - yes or no

The results of these tests are summarized below, and described in detail in Section 5.

Since the same attention-getting devices were used for both the non-time-critical and the time-critical warnings, no measurable difference was found in the mean detection times. The time-critical mean detection times, however, reveal that, when status information was presented graphically, significantly longer mean detection times resulted than when guidance information was presented. This finding suggests that the status messages may cause an increase in the pilots mental workload.

Performance data indicated that the pilots used alert urgency to influence their response. The content as well as the location of the time-critical information proved to be very important to their response. The alerts that provided guidance information graphically in the pilot's primary field of view with voice resulted in the shortest mean response times. On the other hand, the longest mean response times occurred when status information was presented graphically in the pilot's secondary field of view, even though voice was present.

The pilots preferred the guidance information to the status information for time-critical alerts. However, they felt that the graphics used in the study were too cluttered. They believed that the portion of each graphic which provides the guidance information should be emphasized. They had no preference for either of the locations used in the test but said that consideration should be given to using the Electronic Attitude Direction Indicator (EADI) to present the guidance alerts.

2.5 FUTURE DIRECTIONS

This study has dealt with those system functions and components which are directly involved in alerting and informing the crew of abnormal conditions or situations. These functions and components should be standardized among the different aircraft types. However, there are other parts of the total alerting system which are airplane-specific and were not investigated or resolved in this study. Included in this larger system are such things as: fault sensors and sensor combinations, the definition and categorization of specific alerts; the logic used to prioritize and inhibit alerts; the logic for multiple failure conditions, and the allocation of computing functions.

Aircraft or operational-specific considerations should be included in the alerting system design. Examination of existing accident/incident data could identify factors contributing to accidents and incidents, and the role, if any, that the alerting system plays should be assessed. A second area of consideration is the environment in which the system must function. This includes such operational considerations as: alert frequency; crew responses; alert system operation; flight deck operations and activity; crewmember responsibilities, and user opinion of current line-pilots system needs. Investigations in these two areas could assess the potential for the alerting system to monitor the aircraft for malfunctions and failures, to anticipate problems, and expedite resolution of problems.

Another area which requires further investigation is the formatting of the time-critical alerts. Improperly designed displays and display formats can confuse and impede pilot responses, whereas proper designs can have the opposite effect. Near-term requirements for time-critical display of collision avoidance, windshear and perhaps active control failures are anticipated.

Alert prioritization and inhibition schemes can promote more efficient information handling. Both are highly dependent on the specific aircraft type. Methods and techniques for developing these schemes should be identified to aid in future system design.

Computer and display technology have reached a point where the manipulation and presentation of checklist and procedural information should be reviewed with the prospect of improving crew response to emergencies. Areas of interest include display format, checklist accessability, and the possibility of providing checklist information formulated directly from computer logic to aid the crew in responding to multiple failure situations.

Finally, flight test validation should be used to further refine these guidelines.

3.0 TEST FACILITY

The various study requirements dictated the use of a facility in which a flight deck system could be integrated, tested and evaluated in a simulated environment. This facility consists essentially of a generic cab that serves as an "operational breadboard" to facilitate the development of flight deck system concepts, functional capabilities, and interface features. Proposed systems, system changes, and alternative mechanizations can be evaluated and demonstrated in such a facility. It also provides a flexible experimental simulation laboratory that allows for easy introduction of new hardware and change to the flight deck system configuration. System software is modularized to facilitate change; interface equipment is flexible and thus allows for wide varieties of engineering developmental evaluations. These elements have been designed into the Boeing Company's Kent Flight Simulation Center and the Douglas Aircraft Digital Equipment Technology Analysis Center (DETAC). See Figures 3.0-1 and 3.0-2 for illustrations of these facilities. For more detailed descriptions refer to Appendix A.

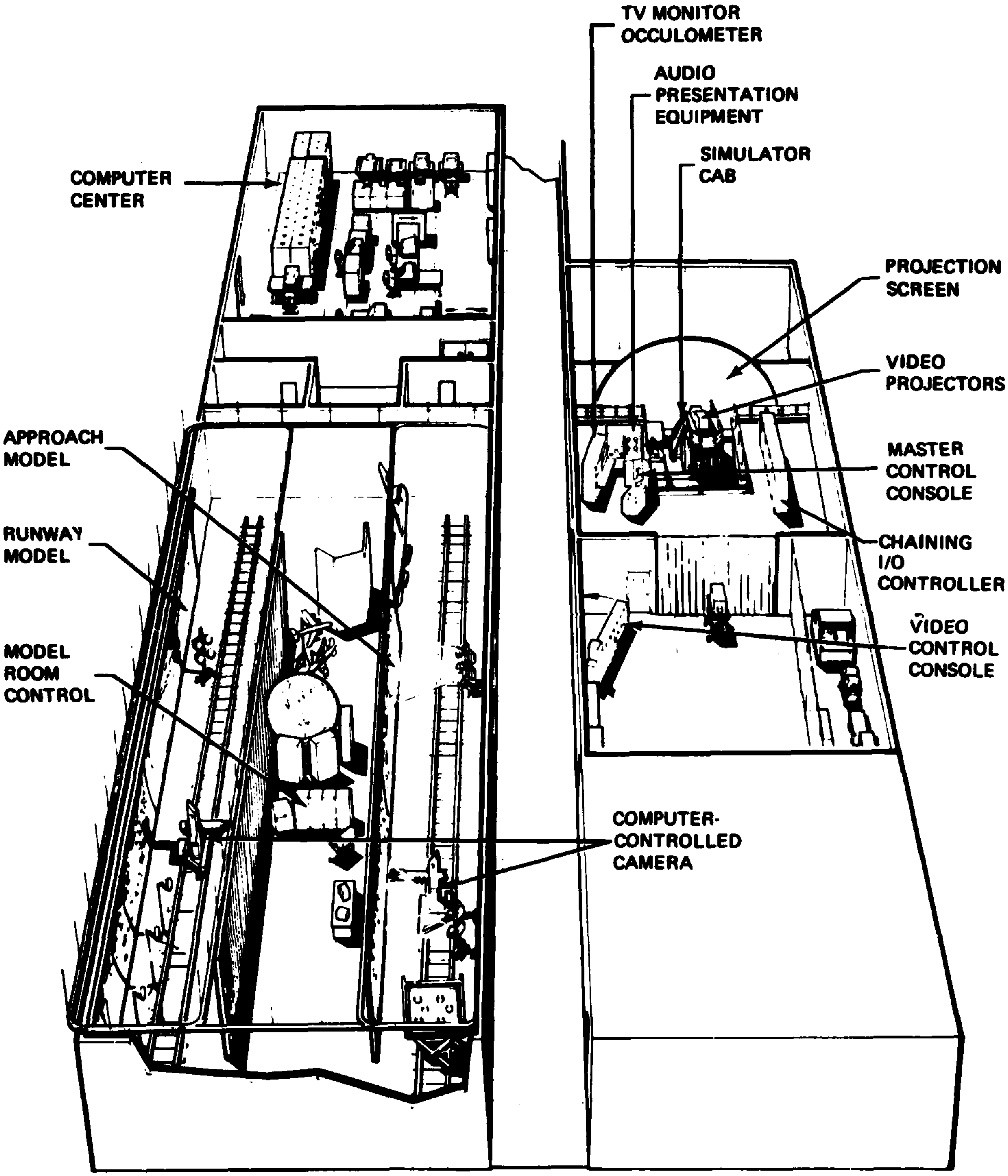


Figure 3.0.1. Kent Visual Flight Simulation Center

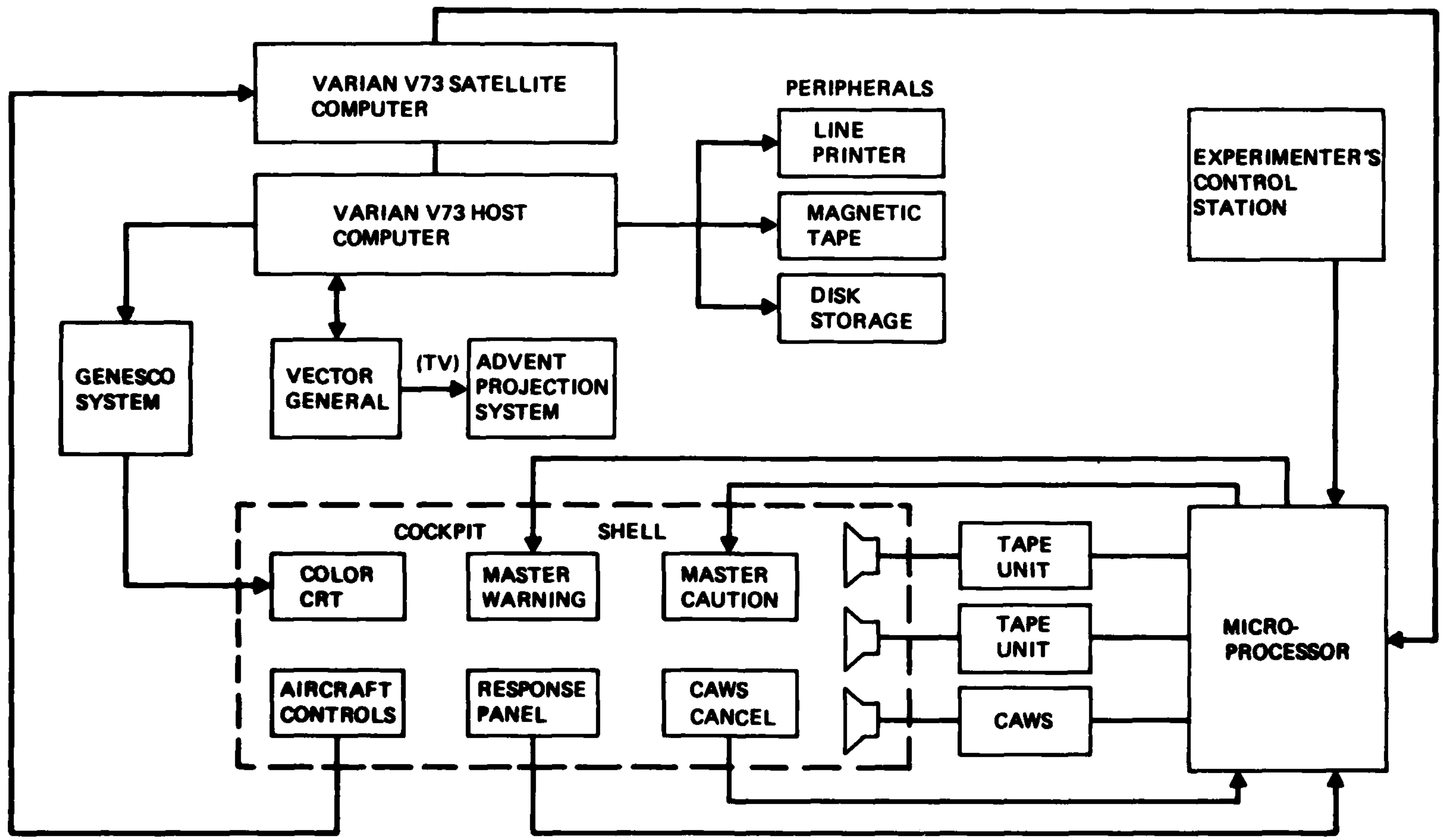


Figure 3.0-2. Douglas DETAC Hardware Configuration for Aircraft Alerting Systems Standardization Study

4.0 SUPPLEMENTAL SIMULATOR TESTS

4.1 INTRODUCTION

A number of unresolved issues were identified during Phase 1 of this study that needed to be resolved prior to Phase 3 testing. In view of this, a set of supplemental tests were conducted and the results were incorporated into Phase 3 testing.

Each of the supplemental tests belonged in one of two categories. The first involved unresolved issues related to system displays and controls; the second addressed unresolved issues relating to system logic. Emphasis was given to alert prioritization, flight phase inhibit logic, alert formatting and interactive functions.

Analytical data was collected from pilots experienced in both commercial airline procedures and engineering/flight test operations.

4.1.1 SYSTEM COMPONENT TESTS

The tests conducted in Phase 1 identified several cases where more than one viable option in system component design selection did exist. These alternative designs were presented to a number of experienced pilots in a simulator environment. Subsequent to that exposure, pilots were asked to evaluate each alternative, relative to several performance criteria.

4.1.1.1 MASTER VISUAL ALERT—WARNING AND CAUTION

The first test addressed the master visual alert. Some current commercial aircraft employ separate master warning and master caution lights, while others use a single split master light to annunciate both warning and caution level alerts (the top half of the switch for warning; the bottom for caution). The alerting system philosophy under consideration called for the master light to act not only as an attention-getting device, but also as a means by which the alert could be acknowledged and/or cancelled. The issue was that the split master light is desirable from a space-efficient point of view; however,

the possibility that multiple alerts could be cancelled inadvertently represents a potential problem inherent in this configuration.

4.1.1.2 MASTER ALERT—ADVISORY

The second test involved the presence/absence of a visual master advisory alert. By definition, advisory level information requires crew awareness but no time frame is defined for response; consequently a master visual alert may not be required. Pilots were asked if they felt that advisory level information warrants annunciation in their primary field of view. If they considered the presence of a master visual advisory to be an unnecessary distraction, it would not be incorporated into the Phase 3 tests. However, if the majority of pilots stated that advisory level annunciation is needed, a master advisory light would be used for Phase 3 testing.

The issue of master aural alert for advisory information was approached in much the same manner as that for the master advisory light. Pilot recommendations for appropriate combinations of master visual and aural alerts were also solicited.

4.1.1.3 PRESENTATION OF ADVISORY INFORMATION

The third issue addressed was the methodology to be used for the display of advisory level information. Three options were presented: A combination of voice and alphanumeric display or either one separately. If an alphanumeric display were used, advisory level alerts would be presented on the same Cathode Ray Tube (CRT) as would warning and caution level information.

4.1.1.4 INTERACTIVE FUNCTIONS

The fourth area investigated concerned selected alerting system interactive functions. One of these involves the methodology used to store and recall messages from memory. Total store/recall may be a desirable feature as it would reduce the interactive requirements of the system. However, situations may arise where a selective store/recall capability is required. Pilots were asked if one of the two alternatives could handle all flight crew information

requirements or if both were necessary. The second interactive function investigated was the methodology by which procedural information should be obtained. Pilots were asked in what situations procedural information should be provided, the level of detail required and the most appropriate mode of presentation. The third interactive function involved the attenuation/cancellation of aural alerts (tones and verbal messages). It was first necessary to determine whether aural alerts should be cancelled or merely attenuated. After this issue was resolved, it was then necessary to determine whether the attenuation and/or cancellation should be done manually or automatically.

4.1.1.5 VERBAL MASTER ALERT

The last test centered on the use of master verbal versus sound alerts. It has been suggested that the words "warning" and "caution" may be more effective as precursors to corresponding alert messages than would discrete warning and caution sounds. Again, pilots were asked to cite specific operational advantages and disadvantages that might be associated with each of these alternatives.

4.1.2 SYSTEM LOGIC TESTS

In addition to the issues regarding system components, a number of questions were raised relative to the logic by which these components should operate. These questions are presented here along with the general methodology that was used to obtain the answers.

4.1.2.1 PRIORITIZATION

It has been suggested that the gross categorization of alert messages into three main categories (warning, caution and advisory) is not sufficient for conveying essential information to the flight crew. It is felt by some that prioritization of alerts within the three categories would provide valuable information which could be used as an aid in selecting the most critical problem to be addressed. The prioritization would be used primarily on the visual information display. Described simply, the messages in each alert

level would be automatically prioritized by the system computer and when a particular fault occurred, the message would appear on the display in its appropriate position relative to the other messages of the same category already present. With this arrangement, the most important message would always be at the top of the display, regardless of time of occurrence. This is the key advantage for prioritization within gross category level. Flight operations personnel from Douglas, Lockheed and Boeing were employed to assist in the development of a questionnaire to be used as an aid in prioritizing alerts.

4.1.2.2 INHIBIT LOGIC

Another issue addressed was the subject of flight phase inhibit logic. This capability would allow the system to inhibit non-essential information during high workload flight segments. Presently, there is little agreement as to which alerts should be inhibited during each flight phase.

4.1.2.3 VISUAL MESSAGE SYNTAX

A third area of interest was visual message syntax. To date, no systematic effort has been made to verify the consistency of alert message formatting. The objective was to survey the industry to identify the most prevelant alert formatting methodology, if one exists. It was anticipated that the vast majority of alert messages would be structured with the nature of the problem preceding the location or vice versa. Information obtained from this survey was summarized and presented to the pilots. They were then asked to recommend a specific format and to explain their selection rationale.

4.1.1.4 MULTIPLE VERBAL ALERTS

The fourth issue addressed involved the sequencing of multiple verbal alerts. A number of alternatives were presented. One of these prioritizes the alert messages and annunciates only the most severe problem. Subsequent message(s) would be annunciated only after more serious one(s) had been corrected or somehow accommodated. A second alternative would be to introduce the most important message for a fixed number of repetitions, cancel it and introduce

each subsequent message in a similar manner. A third alternative was to annunciate the message "multiple alerts" and direct crew attention to the visual information display for the specific fault messages. Again, the intention was to have experienced pilots evaluate each of the alternatives and, if possible, generate additional alternatives for subsequent evaluation.

4.2 METHODOLOGY

4.2.1 PILOT SAMPLE

A total of 25 pilots participated in the simulator evaluation. They were selected from 5 organizations representing both airframe manufacturers and customer airlines. Collectively, these pilots had experience on aircraft built by each of the major U.S. airframe manufacturers. Table 4.2.1-1 shows the organization and aircraft type represented as well as the mean number of flight hours for the 25 pilots.

Table 4.2.1-1. Organizations, Aircraft Types, and Flight-Hours of Pilots Participating in Supplemental Simulator Evaluation

(a) Organizations Represented

Organization	Number of pilots
Douglas Aircraft Company	5
Boeing Commercial Airplane Company	2
Lockheed California Company	4
Continental Airlines	6
Western Airlines	8
Total	25

(b) Aircraft Types Represented (Vehicle of Most Recent Experience)

Aircraft types	Number of pilots
DC-9	2
DC-10	6
B727	12
B747	1
L1011	4

Note: Mean number of flight-hours: 11,319

4.2.2 FACILITY

The supplemental tests were conducted in the Digital Equipment Technology Analysis Center (DETAC). Several changes had to be incorporated into the DETAC facility to accommodate this activity.

A split legend master warning and caution light was added to the glareshield on the First Officer's side and a master advisory light was installed on the Captain's side. Software modifications were made so that both of these switches would be operational. Additional software changes were made to provide a number of interactive functions which included:

- selective and total store/recall
- access to procedural information
- line advance capability
- attenuation/cancellation of verbal alerts

A more complete description can be found in Appendix A.

4.2.3 PROCEDURE

Two pilots participated in each session which lasted approximately 2 hours. Most of this time was spent in the simulator while the remainder was used in a debriefing session in an area outside the DETAC facility.

Prior to entering the cockpit, the pilots were given a brief summary of the work done to date on the project. Since a majority of the participants were not closely associated with research, this type of description provided them with a perspective from which to evaluate the concepts in question.

Upon entering the DETAC facility, the pilots were asked to seat themselves in the Captain's and First Officer's seats so that both could easily see the systems to be evaluated. The briefing began with an overview of development of crew alerting systems. Then a number of disadvantages inherent in current alerting system design were described. Particular emphasis was given to the annunciator matrix which is present on most current aircraft flight decks.

This overview was followed by a discussion of the potential advantages associated with an advanced alerting system, several components of which were demonstrated during the simulator sessions.

The following features of the alerting system were demonstrated to the pilots:

- New Message Indicator: Identifies and annunciates the most recent message on the display.

- Line Advance Function: Provides a line address capability which enables an operator to call up procedural information for a particular alert. It also provides the capability to store messages selectively in memory.

- Memory and Store/Recall Capability: Non-critical fault messages could be placed in memory by one of 2 methods: all messages stored simultaneously or selectively.

- Deferred Item Indicator: Serves to inform the flight crew that fault messages are stored in memory.

- Page Indicator and Paging Function: Provides an indication that a display overflow has occurred. When the number of alerts exceeds the display capability, the software system automatically provides additional "pages" for the excess faults. The page indicator denotes which page is being viewed.

- Overflow Information Indicators: Informs the operator of the status of an overflow condition, i.e., how many message lines are on the next page.

- Procedure/Checklist Function: Provides the capability to display information to be used to correct the selected failure.

The pilots were given the opportunity to operate each of these functions to familiarize themselves with the control/display dynamics. Illustrations of these features are contained in Appendix B.

Two fault monitoring capabilities were also demonstrated. The first entailed placing a dispatch inoperative item into memory and illustrating how the system would constantly monitor it during flight. As aircraft status changes the alert placed in memory would automatically be brought back to page one of the display. The second feature demonstrated was the capability of the system to handle flight phase prioritization and was illustrated by showing the pilots how a specific fault (hydraulic failure) was automatically re-prioritized as the aircraft transitioned from descent to final approach.

The next function demonstrated was the means by which voice alerts could be attenuated or cancelled. Voice alerts were presented and the pilots were allowed to manually cancel and attenuate the alerts on two successive trials. They also observed while the system automatically cancelled and attenuated the alerts during two additional trials.

The participants were then given a demonstration of the system control options for the master visual alert. This was preceded by a brief summary of the split and separate master visual alerts. Also demonstrated were the location, function and operation of the master visual advisory alert.

Finally, various display formats currently under consideration (see Appendix E) were shown to the pilots on the display screen. Each format was accomplished by a graphic representation of the four formats for purposes of comparison.

Pilots were encouraged to ask questions or make comments at any time. They were also offered repeated demonstrations of any areas that they felt required additional review. All relevant pilot comments were recorded for subsequent documentation.

Following the simulator session, participants were invited to a debriefing area where they were given a questionnaire (debriefing summary) to complete. The questionnaire was structured to solicit pilot opinion for each of the issues. A number of issues were addressed in the questionnaire that were not

demonstrated in the simulator. The first of these was the importance of a master advisory tone. They were also asked about visual information display message syntax and a verbal master aural alert. The advisory tone and verbal alert were not demonstrated in the simulator because it was felt that the pilots would tend to evaluate the actual sounds (tone and words) rather than the concepts behind them. Illustration of alternative visual message syntaxes was restricted to the debriefing summary because demonstration in the DETAC facility would not have provided the pilots with any information or perspective over and above that provided by the questionnaire.

Upon completion of the debriefing summary, an informal discussion took place wherein the pilots asked questions and made comments about various alerting system and aircraft issues. Again, comments relating to the development of advanced alerting systems were recorded.

Before leaving, the pilots were given two additional questionnaires which they were asked to complete and return at their earliest convenience. One of these was a supplemental debriefing questionnaire designed to gather additional information on the alerting system display characteristics currently under consideration. The other questionnaire was concerned with alert prioritization and inhibition. Results from this questionnaire were used to help determine the feasibility of a prioritization scheme and to gain some insight into the problems that might be encountered during development and implementation efforts.

4.3 RESULTS

4.3.1 DEBRIEFING SUMMARY

A copy of the debriefing summary and the pilot responses are contained in Appendix C.

Each of the 25 pilots completed the debriefing summary. Table 4.3.1-1 presents a summary of pilot preferences for each of the issues addressed along with the results of the chi square analysis. Each issue is also addressed separately in the following sections.

Table 4.3.1-1. Summary of Issues, Options, and Significant Pilot Preferences

Issue	Options	Pilot preferences	X^2	Significance level	Comments
Master alert* (warning and caution)	Split master Separate master	11 14	0.36	Not significant	
Master alert (advisory)	Master light Discrete tone Voice Flashing box Master light and tone Master light and voice Master light and flashing box Tone and flashing box Other	4 0 0 3 1 2 12 2 1	25.11	$P < 0.001$	
Advisory information display	Voice Alphanumeric display Voice plus display Other	0 23 2 0	17.64	$P < 0.001$	
Store/recall capability	Total store/recall Selective store/recall Combination (total and selective) Other	8 3 14 0	7.21	$P < 0.05$	Difference between "total" and "combination" not significant
Visual message syntax	Gen heading—subsystem—nature of emer Nature of emer—general heading—subsystem Other	20 3 2	32.76	$P < 0.001$	
Voice alert	Words better than tones Tones better than words No difference	15 9 1	11.84	$P < 0.01$	Difference between "tones better" and "words better" not significant
Multiple verbal alerts**	Prioritize messages Cancel after correction Prioritize messages Cancel after fixed number of repetitions Multiple alerts Other	8 0 14 3	18.03	$P < 0.001$	Difference between two most preferred options not significant
Cancellation/attenuation of aural alerts**	Automatic attenuation Manual attenuation Automatic cancellation Manual cancellation	2 0 4 19	36.0	$P < 0.001$	

* The pilots did not show a clear preference for either the split or separate master lights. Fourteen preferred separate master lights; the remainder (11) favored the split concept.
** No. 1 rankings.

4.3.1.1 MASTER VISUAL ALERT—WARNING AND CAUTIONS

For warning and caution level alerts, the pilots did not show a clear preference for either the split or separate master light. While a majority preferred the separate master visual indicator switch, this difference was not statistically significant.

4.3.1.2 MASTER ALERT—ADVISORY

There was a decided preference (12) for a master advisory light in conjunction with a flashing box around the most recent message. A chi square test for goodness of fit showed that this preference was highly significant ($X^2 = 25.11 < .001$). This was the only option preferred by more than 4 pilots.

4.3.1.3 PRESENTATION OF ADVISORY INFORMATION

A vast majority of the pilots (23 of 25) preferred the alphanumeric display over voice or a combination of the two to annunciate advisory information. Again, this preference was highly significant ($X^2 = 17.64; p < .001$).

4.3.1.4 INTERACTIVE FUNCTIONS

When questioned about system memory requirements, 14 pilots preferred a combination of total and selective store/recall. A chi square test for goodness of fit between the three options listed showed this preference to be statistically significant ($X^2 = 7.21; p < .05$). When a chi square was computed for the two most frequent choices, the result was not statistically significant.

4.3.1.5 PROCEDURAL/CHECKLIST INFORMATION

When asked to judge the automatic checklist/procedural information features, a significant majority (23 of 25) felt that this capability would be good to excellent. This question elicited a number of useful suggestions from the pilots that could be implemented in future work on procedural/checklist information displays, (See Appendix B).

4.3.1.6 ATTENUATION/CANCELLATION OF AURAL ALERTS

The clear preference (19 out of 25) was for manual cancellation. This preference was highly significant ($X^2 = 36.0$; $p < .001$). The remaining 6 pilots preferred either automatic volume reduction (2) or automatic cancellation (4) after a fixed number of repetitions.

4.3.1.7 VISUAL MESSAGE SYNTAX

Regarding visual message syntax, a majority of the respondents (20 out of 25) preferred the format that showed the general heading followed by the subsystem and nature of the emergency. This highly significant preference ($X^2 = 32.76$; $p < .001$) may be explained in part by the fact that the most preferred option was also the example provided in the question (see Appendix B).

4.3.1.8 VERBAL MASTER ALERT

A majority of the pilots (15 out of 28) favored words rather than a discrete sound for the aural master alert. This preference, however, was not statistically significant.

4.3.1.9 MULTIPLE VERBAL ALERTS

Most pilots (14 out of 25) preferred introduction of the message "multiple alerts". Although the overall difference in preference between the four options was highly significant ($X^2 = 18.03$; $p < .001$), the difference between the two most preferred options was not significant (where the second most preferred option was to prioritize messages and annunciate only the most severe problem and annunciate subsequent message(s) only after the previous one had been corrected or somehow accommodated).

4.3.2 SUPPLEMENTAL QUESTIONNAIRE

All pilots who participated in the supplemental simulator evaluations were asked to rate a number of additional system capabilities and characteristics which are shown in Appendix B.

A total of 17 pilots completed and returned the supplemental questionnaire. The questionnaire along with the mean ratings for each question can be found in Appendix D. Table 4.3.2-1 shows the organizations represented in this group, along with the mean number of flight hours and the most recent aircraft experience of the pilots surveyed.

Four display formats were evaluated, which can be described as follows:

1. Reverse chronology within color: New message appears at the top of its alert group (color coded urgency level).

2. Priority: New message appears at a pre-determined location within its alert group depending on its priority level.

3. Chronology within color: New message appears at the bottom of its alert group.

4. Chronology: Most recent message appears at the top of the list, regardless of color or specific priority level.

Figure 4.3.2-1 illustrates how the display would look using each of the alternative formats. Two failures from each urgency level (warning, caution, advisory) occurred in the following order:

1. Gen Bus 3 Fail - Caution (Amber) - (First failure to occur)
2. AC Bus 3 Off - Caution (Amber)
3. Pack 3 Off - Advisory (Blue)
4. Cabin Altitude - Warning (Red)
5. L. Emer. AC Bus - Warning (Red)
6. Flap Limit Inop - Advisory (Blue) - (Last failure to occur)

The pilots were asked to evaluate 4 display formats (Figure 4.3.2-1) relative to 5 separate questions. As can be seen in Figure 4.3.2-2, they considered 4 of the 5 questions to be somewhat to very important. Relative to these 4 criteria, the trend shows a preference for the format employing reverse chronology within color. This was not, however, a significant preference, as illustrated by the overlap of the 95% confidence limits.

Table 4.3.2-1. Organizations, Aircraft Types, and Flight-Hours of Pilots Completing the Supplemental Questionnaire

(a) Organizations Represented

Organization	Number of pilots
Douglas Aircraft Company	4
Boeing Commercial Airplane Company	2
Lockheed California Company	4
Continental Airlines	4
Western Airlines	3
Total	17

(b) Aircraft Types Represented (Vehicle of Most Recent Experience)

Aircraft type	Number of pilots
DC-9	4
DC-10	1
B727	8
L-1011	4

Note: Mean number of flight-hours: 13,019

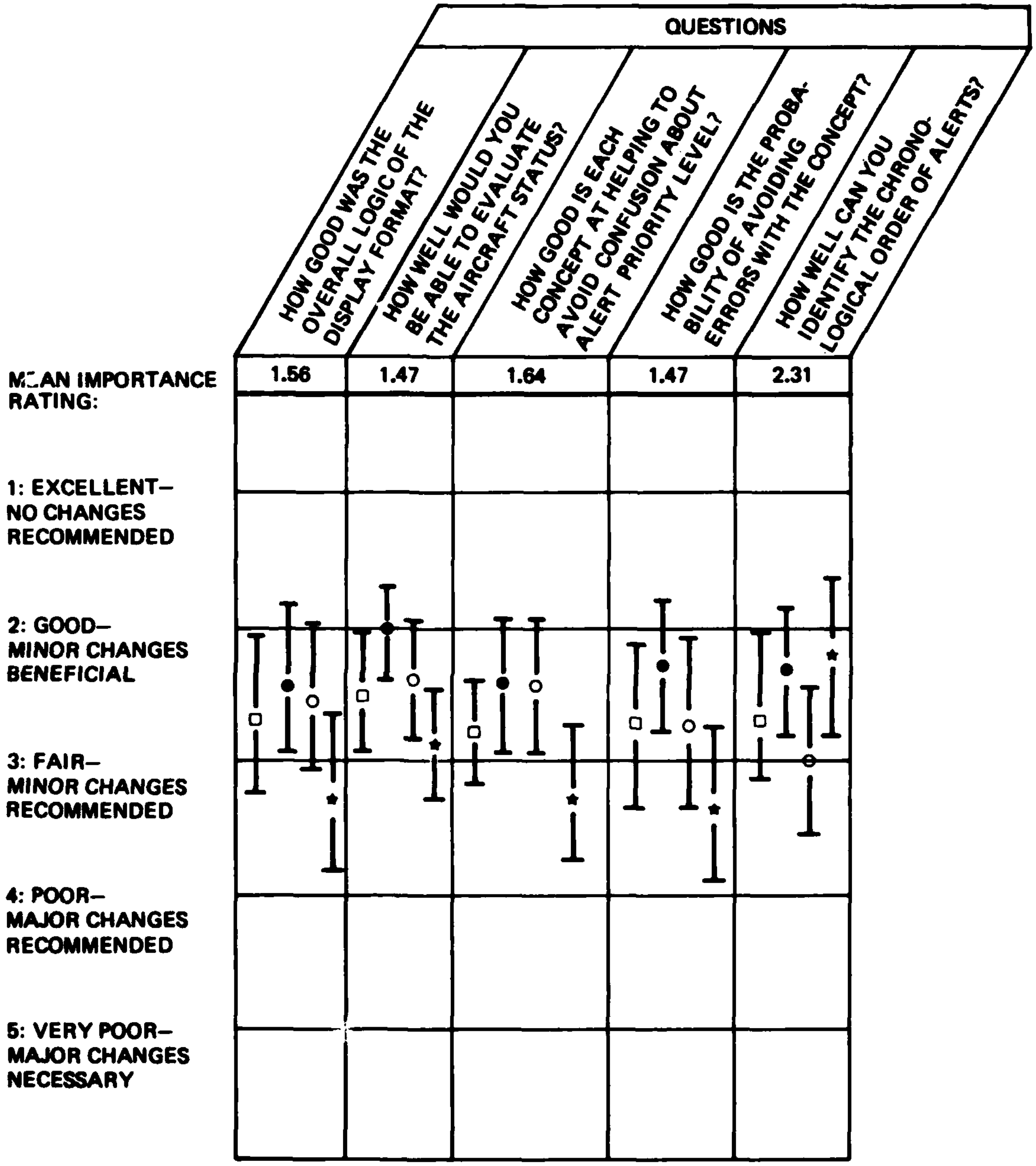
Reverse chronology within color	Chronology within color
(R) L EMER AC BUS	(R) CABIN ALTITUDE
(R) CABIN ALTITUDE	(R) L EMER AC BUS
(A) AC BUS 3 OFF	(A) GEN BUS 3 FAIL
(A) GEN BUS 3 FAIL	(A) AC BUS 3 OFF
(B) FLAP LIMIT INOP	(B) PACK 3 OFF
(B) PACK 3 OFF	(B) FLAP LIMIT INOP

Priority	Chronology
(R) L EMER AC BUS	(B) FLAP LIMIT INOP
(R) CABIN ALTITUDE	(R) L EMER AC BUS
(A) AC BUS 3 OFF	(R) CABIN ALTITUDE
(A) GEN BUS 3 FAIL	(B) PACK 3 OFF
(B) PACK 3 OFF	(A) AC BUS 3 OFF
(B) FLAP LIMIT INOP	(A) GEN BUS 3 FAIL

Legend:

(R) Red
(A) Amber
(B) Blue

Figure 4.3.2-1. Display Formats



Key:

Importance rating scale

1: Very important
2: Somewhat important
3: Neither important nor unimportant
4: Somewhat unimportant
5: Very unimportant

Display format

□ Chronology within color
● Reverse chronology within color
○ Priority
★ Basic chronology

Figure 4.3.2-2. Mean Pilot Ratings for Overflow Logic Options (With 95% Confidence Limits)

Pilot judgements were solicited on a number of other display characteristics. The results can be summarized as follows:

- Overall character word and line spacing was judged as being good to excellent.

- Stroke width was fair to good.

- The contrast between the red (warning) and amber (caution) messages, and the display screen was good to excellent.

- The blue (advisory) messages and the white ancilary information (mode, page and deferred item indicators) were fair to good relative to background brightness.

- The location, color and meaning of the alert/memory mode indicator was judged as being fair to good.

- Pilots preferred the colored box over the asterisk as a new message indicator.

- The page number indicator was fair to good in terms of location, size, clarity of meaning and contrast with alert messages.

- The cursor (line advance indicator) was good to excellent relative to size and contrast with alert messages while it was seen as being fair to good in terms of shape and key input dynamics.

- The size, shape, location, contrast, and flash rate of the colored boxes used to indicate the presence of an overflow condition were judged as being good. In terms of clarity, they were seen as being fair to good.

- The deferred item indicator (in memory symbol) size, shape, location and clarity of meaning was viewed as being fair to good.

- Pilots rated the function keys as good to excellent in terms of size shape and location while contrast and correspondence of display dynamics to key inputs were judged as being fair to good.

- The line keys were rated as being fair to good relative to size, shape, location, contrast and display dynamics.

- The use of color to differentiate between warning, caution and advisory messages was judged as being good to excellent in terms of clarity and as an aid in evaluating aircraft status.

4.3.3 ALERT PRIORITIZATION AND INHIBIT QUESTIONNAIRE

A total of 21 pilots from 5 organizations completed and returned this questionnaire. Table 4.3.3-1 shows the organizations which these pilots represented as well as their most recent aircraft experience and the mean number of flight hours for the group.

4.3.3.1 ALERT PRIORITIZATION

Figure 4.3.3.1-1 illustrates the questionnaire form. All information required to complete the questionnaire is contained on the form. Mean pilot ratings for 2 of the 16 alerts ("Antiskid Left Inboard Failure" and "APU Fire") are illustrated in Figures 4.3.3.4-2a and -2b respectively. In Figure 4.3.3-2a (Antiskid Left Inboard Failure"), priority ratings for flight segments D and E (initial climb and climb-cruise-descent) were significantly lower than for the other flight phases; the 95% confidence limits for flight phases D and E do not overlap with those for the other flight segments. The point to be made here is that flight phase inhibit logic may be necessary when alert priority is not consistent across flight phases. Figure 4.3.3-2b, however, shows that the pilots rated the priority of the "APU Fire" alert consistently across all flight phases. Appendix E presents the information obtained from this questionnaire. Additional examples of overlapping/non-overlapping priorities can be found; also to be found are alerts that were rated as cautions in some flight phases and warnings in others.

Table 4.3.3-1. Organizations, Aircraft Types, and Flight-Hours of Pilots Completing the Alert Prioritization and Inhibit Questionnaire

(a) Organization Represented

Organization	Number of pilots
Douglas Aircraft Company	7
Boeing Commercial Airplane Company	2
Lockheed California Company	3
Continental Airlines	4
Western Airlines	5
Total	21

(b) Aircraft Types Represented (Vehicle of Most Recent Experience)

Aircraft type	Number of pilots
DC-9	3
DC-10	5
B727	9
B747	1
L-1011	3

Note: Mean number of flight-hours: 11,669

Across the 8 flight phases, 13 of the 16 alerts were rated as cautions by the pilots. Figure 4.3.3.1-3 shows how the pilots rated these 16 alerts for the final takeoff phase. In looking at the 95% confidence limits, it is apparent that no clear overall preference was given for prioritizing the alerts. Ratings of the alerts for the other seven flight segments can be found in Appendix E.

4.3.3.2 INHIBIT LOGIC

Table 4.3.3.2-1 summarizes the inhibit preferences for all 16 alerts across the 8 flight phases as well the percentage of pilots who saw the further need to consider aircraft configuration in the inhibit logic scheme. The number shown in each box represents the percentage of pilots who felt that inhibition should be employed for that alert during that particular flight phase.

MAIL COMPLETED
QUESTIONNAIRE TO: David Po-Chedley
Mail Code 35-36
Douglas Aircraft Co.
3855 Lakewood Blvd.
Long Beach, CA 90846

ALERTS	A TAXI	B INITIAL TAKEOFF	C FINAL TAKEOFF	D INITIAL CLIMB	E CLIMB, CRUISE, DESCENT	F INITIAL APPROACH	G FINAL APPROACH	H LANDING/ ROLLOUT	COMMENTS/CONFIGURATION EXCEPTION
1. ANTISKID L INBD FAIL									
2. APU FIRE									
3. L FUEL DUMP VALVE OPEN									
4. BATTERY BUS OFF									
5. GEN OFF									
6. GALLEY OVERHEAT									
7. APU GEN OFF									
8. CABIN PRESS RELIEF VALVE OPEN									
9. WING ANTI-ICE DISAGREE									
10. AIR COND PACK OFF									
11. DUCT AVIONIC COMP OVERHEAT									
12. ENG FIRE									
13. L EMER AC BUS OFF									
14. GPWS									
15. MANIFOLD FAIL (PNEU)									
16. CABIN ALT									
17.									
18.									

Flight History Data

Name ______________________________

Age ____________ Flight-hours ____________

In the spaces below indicate the types of aircraft you have flown. Put a "1" above the aircraft type you have flown most recently, a "2" above the next, etc.

___ 1-(DC-9) ___ 2-(DC-10) ___ 3-(B707) ___ 4-(B727) ___ 5-(B737) ___ 6-(B747) ___ 7-(L1011) ___ 8-(Other)

Aircraft type most familiar with ______________________
(questionnaire should be completed relative to this aircraft type)

Organization represented ______________________

Alert definitions

Warning: Emergency or operational aircraft systems conditions that require immediate corrective or compensatory action by the crew

Caution: Abnormal operational or aircraft systems conditions that require immediate crew awareness and subsequent corrective or compensatory crew action

Key:

Rating Scale

40 to 79 caution-level alerts

80 to 99 warning-level alerts

Flight Phase Definitions

A: Taxi
B: Initial takeoff—0 kn to V_1—30
C: Final takeoff—V_1—30 to 400 ft
D: Initial climb—400 ft to 1,500 ft
E: Climb, cruise, descent
F: Initial approach—1,500 ft to 200 ft
G: Final approach—200 ft to touchdown
H: Landing/rollout—touchdown to taxi

Flight Phase Inhibit Definitions

A: Inhibit all components of the alert
C: Inhibit selected alert component(s), but not all of them

Figure 4.3.3.1-1. Alert Prioritization and Inhibit Questionnaire Rating Form

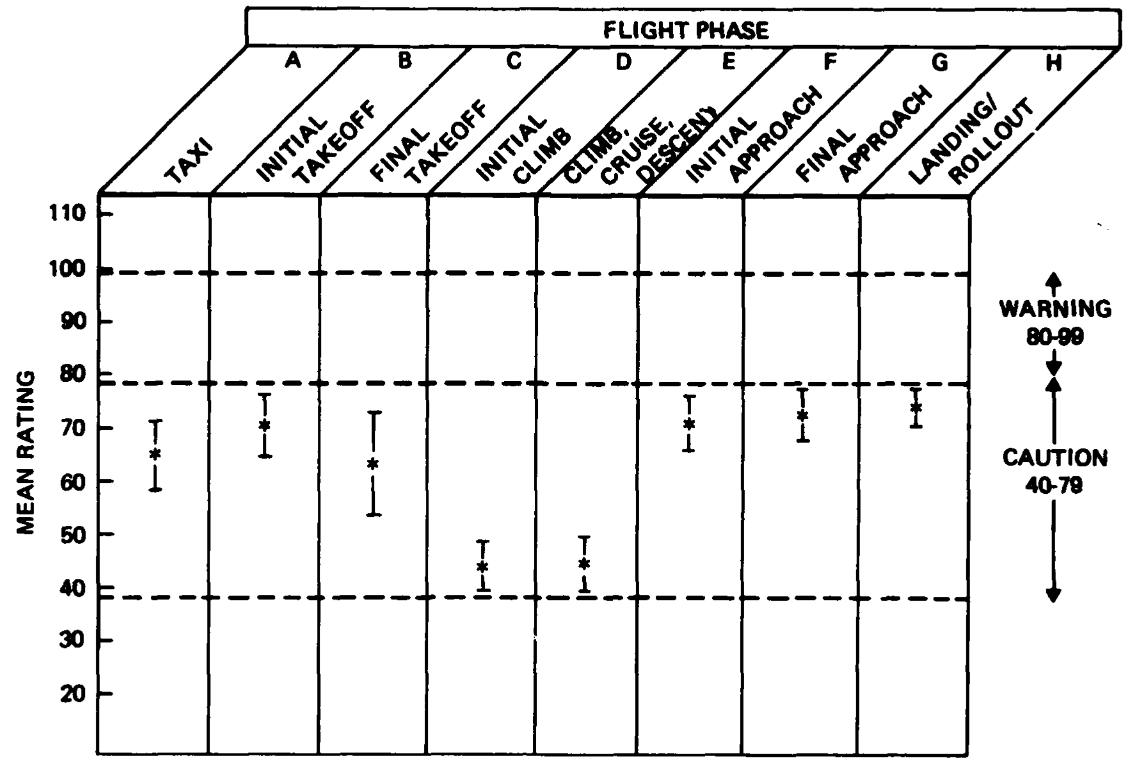


Figure 4.3.3.1-2a. Means and Confidence Limits for Pilot Ratings of Selected Alerts—Antiskid L Inbd Fail

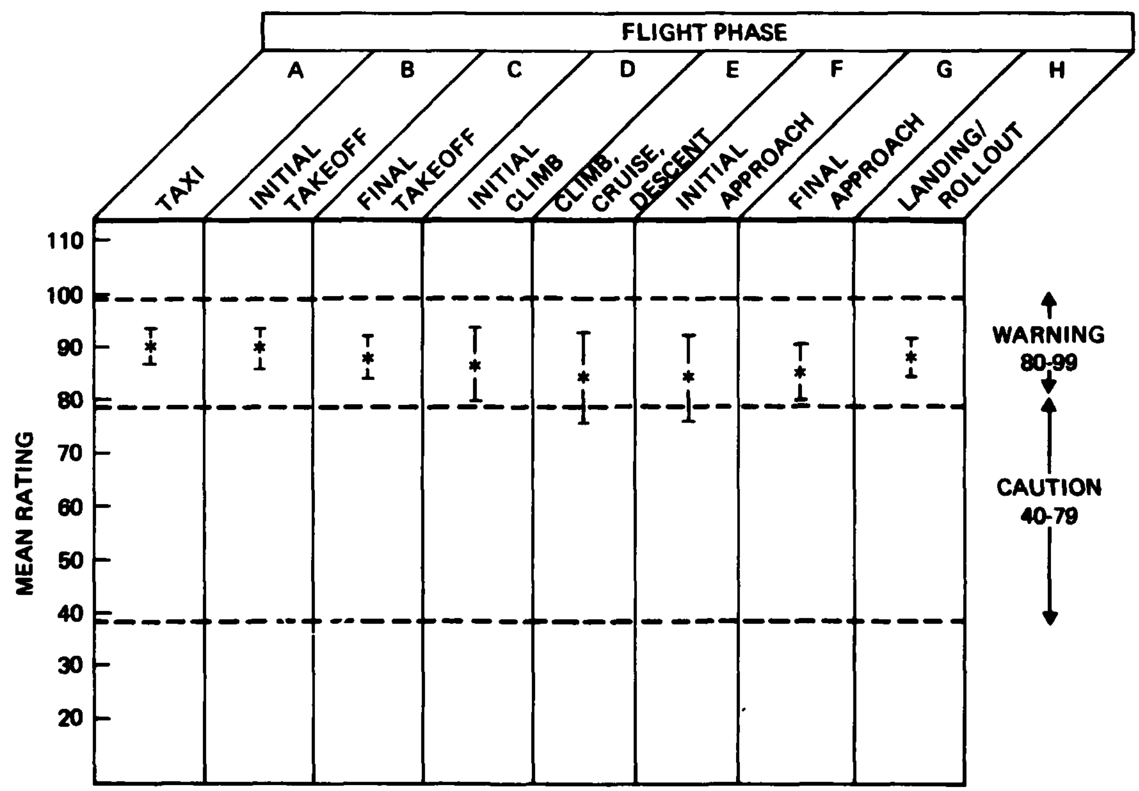


Figure 4.3.3.1-2b. Means and Confidence Limits for Pilot Ratings of Selected Alerts—APU Fire

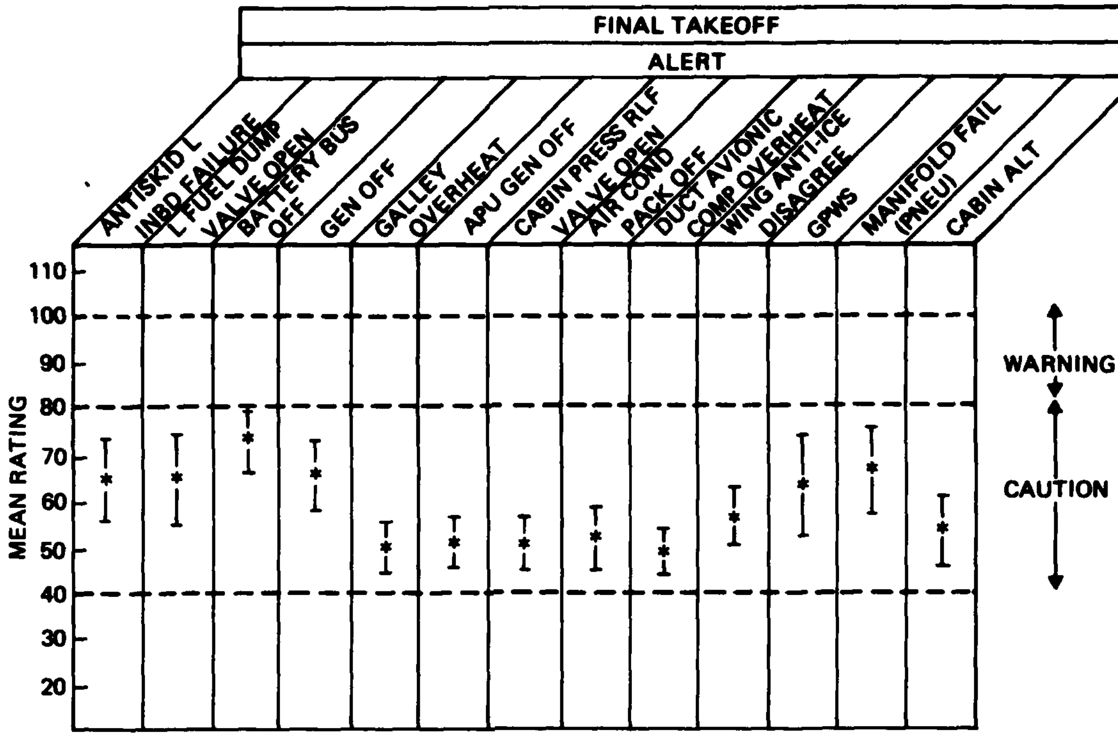


Figure 4.3.3.1-3. Means and 95% Confidence Limits for Pilot Ratings of Selected Caution Level Alerts

Of the 128 percentage values for the eight flight phases shown in Table 4.3.3.2-1 only 23 (18%) were identified as requiring inhibit logic by a majority of the pilots questioned. Overall, there was little agreement as to which alerts should be inhibited during each flight segment. There was more agreement as to when alerts should not be inhibited; in several cases 80 to 90% of the pilots felt that inhibition would be inappropriate. Conversely, there was only one case where more than 70% of the pilots agreed on the need for alert inhibition.

It may seem surprising that approximately 50% of the pilots felt that a fire warning should be inhibited during final take off and final approach. It should be noted that pilots were given the option of selecting either partial or total alerting medium inhibition. Inspection of the raw data revealed that 90% of the pilots that favored inhibiting the fire alert during final takeoff and final approach preferred that only one component of the fire warning be withheld. Responding pilots suggested that they would want the fire bell inhibited while the glareshield light would remain operational.

Of the 16 alerts, there were only 4 for which one third or more of the pilots saw a need for some type of aircraft configuration exception. There were, on the other hand, 9 cases where 80% to 95% of the pilots saw no need for any configuration exceptions.

*Table 4.3.3.2-1. Alert Inhibit Logic Summary**

ALERTS	FLIGHT PHASE								
	A	B	C	D	E	F	G	H	
	TAXI	INITIAL TAKEOFF	FINAL TAKEOFF	INITIAL CLIMB	CLIMB, CRUISE DESCENT	INITIAL APPROACH	FINAL APPROACH	LANDING/ ROLLOUT	CONFIGUR-ATION EXCEPTIONS
1. ANTISKID L INBD FAIL	19	19	47	47	42	20	28	28	28
2. APU FIRE	10	25	50	25	25	30	35	28	33
3. L FUEL DUMP VALVE OPEN	24	29	52	43	33	33	25	35	19
4. BATTERY BUS OFF	15	25	40	40	20	30	35	25	25
5. GEN OFF	10	15	35	25	10	20	40	30	50
6. GALLEY OVERHEAT	19	42	57	52	23	33	42	33	5
7. APU GEN OFF	25	40	60	50	35	40	55	36	20
8. CABIN PRESS RELIEF VALVE OPEN	28	47	57	47	24	33	57	45	10
9. WING ANTI-ICE DISAGREE	38	47	57	43	28	38	48	48	19
10. AIR COND PACK OFF	24	43	57	57	29	43	52	43	57
11. DUCT AVIONIC COMP OVERHEAT	15	35	60	50	25	35	45	30	5
12. ENG FIRE	14	19	47	38	14	29	52	33	33
13. L EMER AC BUS OFF	25	35	40	35	20	30	30	30	15
14. GPWS	32	42	47	42	37	32	47	52	10
15. MANIFOLD FAIL (PNEU)	23	33	57	42	23	33	47	38	10
16. CABIN ALT	45	55	66	52	14	47	71	60	10

*Percentage of pilots who favored alert inhibition during each flight phase, and percentage who foresaw the need for configuration exceptions for each alert.

4.4 DISCUSSION

4.4.1 DEBRIEFING SUMMARY RESULTS

Most of the data collected during this series of tests supports previous research on alerting system design. This is encouraging when it is considered that a majority of the pilots who participated were not closely associated with research such as this. It was thought that many of the line pilots who participated would see inconsistencies between what they observed in the simulator and what they actually experience while flying the line. Whenever a number of advanced concepts are demonstrated individually, rather than as parts of a cohesive alerting system, pilots sometimes view them as being somewhat disjointed and confusing. Fortunately, the opposite was true for this study. The participants had little trouble integrating these concepts with their experiences and providing some valuable inputs for future system development.

There was no clear preference for either the split or separate master light, so it was decided that the split version of the master visual alert would be used for the Phase 3 tests. This choice was consistent with the conventional alerting system configuration that was used in Phase 3. This configuration is used in 2 of the 3 major wide body U.S. aircraft.

By a wide margin, the pilots preferred a master light in conjunction with a flashing box for annunciation of advisory level alerts. It was agreed that this arrangement would be employed in the Phase 3 tests along with a discrete master advisory sound. Available guidelines for alerting system design recommend the use of a distinct sound for each alert priority level (Randle, Larsen and Williams, 1980; Boucek, Veitengruber and Smith, 1976; MIL-STD-411D, 1967; and MIL-STD-1472B, 1978). During high levels of visual workload, a distinct sound will provide additional sensory input, and, if carefully chosen, can provide extremely effective noise penetrating characteristics as well as preliminary information on the relative severity of the particular alert.

Regarding the advisory visual information display, pilots clearly preferred an alphanumeric visual display. In Phase 3, advisory level alerts were presented on the same visual display used for warning and caution level alerts. Although a majority of the pilots chose a combination of selective and total store/recall, this preference was not significant. The store/recall feature in the alerting system was not intended to be evaluated objectively in Phase 3; however, a demonstration of total store/recall was provided. Accommodation of voice alerts in Phase 3 testing was provided in a manner consistent with pilot recommendations. A vast majority of the pilots preferred manual cancellation of voice alerts over all the other alternatives. Manual cancellation was used in both the conventional and advanced alerting systems.

In addressing the subject of visual message syntax, it was determined that using one syntax for all alert messages would be extremely awkward. Although a significant majority of the pilots favored the "heading-subsystem-nature of problem" configuration, this syntax does not lend itself well to all alert messages. The conclusion drawn is that standardization should be the goal but a clear statement of the problem is an imperative prerequisite.

The issue of verbal alert generated some rather interesting results. Most of the pilots (though not a significant majority) favored voices over discrete tones. This was particularly surprising since a majority of the pilots had never been exposed to this concept before. As mentioned earlier, the available literature suggests that a precursor tone is effective in its attention-getting capability. For this reason, the precursor tones were used in the Phase 3 testing. However, it is hoped that the unexpected pilot acceptance of master voice alerts will encourage research efforts aimed at measuring the relative effectiveness of these two alerting concepts.

Regarding multiple verbal alerts, most of the pilots questioned favored introduction of the message "Multiple Alerts" in cases where 2 or more alerts occur simultaneously. This option appeared to be the most viable in terms of facilitating crew awareness of the situation as well as being conducive to expedient corrective action. The other two options required a prioritization scheme which is not presently available in an accurate and reliable form. For these reasons, the option preferred by a majority of pilots was implemented for Phase 3 activity.

4.4.2 SUPPLEMENTAL DEBRIEFING QUESTIONNAIRE

Responses to the supplemental debriefing questionnaire indicate that, for the most part, pilots were satisfied with the preliminary development of the central display unit. The overall trend was toward a preference for the display format employing reverse chronology within alert urgency level. This format was incorporated into the Phase 3 testing.

4.4.3 ALERT PRIORITIZATION AND INHIBIT QUESTIONNAIRE

There are a number of conclusions to be drawn from the results of the alert prioritization and inhibit questionnaire. It seems likely that prioritization and inhibit systems need to be aircraft and possibly airline specific as there was wide variability of ratings among pilots for the 16 alerts used in the questionnaire. There may be two explanations for this situation. The first is that the pilots who participated in this study represented quite a variety of experience and backgrounds which was generally a function of the airline and aircraft types flown. The number of aircraft types represented, may have caused the large amount of the observed variability. Secondly, there may have been a certain amount of disagreement among pilots as to the relative importance of various alerts that was not due to specific aircraft experience. Even with subject variability taken into account, the data suggests the need for a prioritization system that is flight phase adaptive. This is consistent with recommendations made by other researchers (Randle, Larsen and Williams, 1980).

In developing an effective, reliable prioritization system, a more precise methodology is needed. In looking at the graphic representations of the pilot responses, it is clear that construction of a useful prioritization scheme would be impossible using this data. It may be that other organizations such as Reliability and Safety could provide precise data that would be used to generate an effective prioritization system.

There was also very little agreement among pilots as to which alerts should be inhibited during each flight phase. Although a good percentage of pilots favored inhibition of relatively serious fault messages during the final

takeoff and final approach flight segments, 90% of those who felt this way, however, favored inhibition of only one component of the alert.

Alert prioritization and inhibit systems are in an early stage of development. Additional research should be conducted on subjects such as alert sequencing, inhibit justification and requirements for aircraft specific systems.

5.0 SYSTEM SIMULATION TESTS

The primary purpose of the Phase 3 testing effort, as originally defined, was to evaluate the candidate alerting concepts developed in Phase 1, and to identify those candidates which were valid alternatives to conventional alerting techniques. These candidate concepts were then to be translated into alerting system design guidelines. Due to the high level of agreement achieved among the working committee members concerning the conceptual system, the number of alternative alerting concepts was smaller than anticipated. This fact, combined with the identification of two other major areas of interest, the flight engineer's station and time-critical warnings, resulted in a modification of the original simulation test program.

The system validation portion of the simulation program was conducted as planned; pilot performance using the two alternative advanced crew alerting systems was evaluated in comparison to a conventional system. The flight engineer's performance using an advanced display was also compared to a conventional system to validate the advanced concept. Finally, a test was designed to evaluate various presentation media, formats and locations for those warnings which have highly time-critical response requirements, such as, ground proximity, collision avoidance, windshear. Each of the objective tests, supplemented with a questionnaire to obtain pilot opinions was analyzed and the findings were incorporated into the alerting system guidelines. The following sections describe these tests, conducted in the Boeing Visual Flight Simulator, and summarize the results.

5.1 TEST OBJECTIVES

5.1.1 SYSTEM VALIDATION

The first objective of the Phase 3 tests was to evaluate the candidate alerting system concepts to determine their validity with respect to: 1) the objectives of a crew alerting system, 2) the assumptions upon which the systems were based, 3) the functioning of the system components in a simulated real-world setting, and 4) the acceptability of the system by the users. Therefore, tests and evaluations were designed to answer the following questions concerning the validity of the candidate alerting concepts.

1. Do the candidate concepts meet the assumptions set forth concerning advanced systems (see Table 1.0-1)?

2. Do the candidate concepts meet the objectives of an alerting system (see Section 1.0)?

3. Do the concepts enable equal or better pilot detection and response performance than a conventional alerting system?

4. Is the information provided by the advanced systems equal to or better than that provided by a conventional alerting system?

5. Is the flight engineer's performance with the advanced system equal to or better than performance with a conventional system?

6. Are the detection and response times for the different urgency levels affected by the system used?

7. How often is voice used in candidate system B? How can voice best be used in advanced alerting systems?

8. How do the pilots who fly with the advanced systems rate them with respect to conventional systems?

5.1.2 TIME-CRITICAL WARNING

A second objective in the Phase 3 tests was to define alerting methods which would enable the pilot to respond quickly and accurately to situations which are extremely time-critical. With this objective, tests and evaluations were designed to answer the following questions:

1. Is a time-critical display needed?

2. Does the location of the time-critical display have an effect on detection time, response time, and/or missed alerts?

3. Is there any difference in response performance when the alerts are presented graphically, alphanumerically or by a combination of the two?

4. Do responses change as a function of different combinations of display location and presentation formats?

5. Is there an effect on response performance when the message format provides the pilot with guidance (e.g., PULL UP), rather than status information (e.g., TERRAIN)?

6. What is the effect on detection and response performance with the presence or absence of the voice message?

7. Do time-critical warnings have a disruptive effect on flight performance?

5.2 EXPERIMENTAL DESIGN

The basic experimental design was a factorial analysis of variance with repeated measures. The following sections present the specific designs for each test and the variables chosen for study.

5.2.1 SYSTEM VALIDATION TESTS

The validation tests compared pilot performance on the advanced and conventional systems. There were three validation tests. Each of two advanced alerting pilot systems were compared to a conventional system; an advanced flight engineer system was compared to a conventional system. Each of the pilots used one of the advanced systems for two flights and the conventional system for two flights. Half of the pilots flew concept A and half concept B, to negate possible confounding effects.

Figure 5.2.1-1 illustrates the arrangement of the alerting components for the candidate systems. Each system consisted of three components. The first was a split legend master visual alert located in the pilot's primary field of vision. The upper half of the master alert was red and labelled WARNING; the lower half was amber and labelled CAUTION. The second component was the

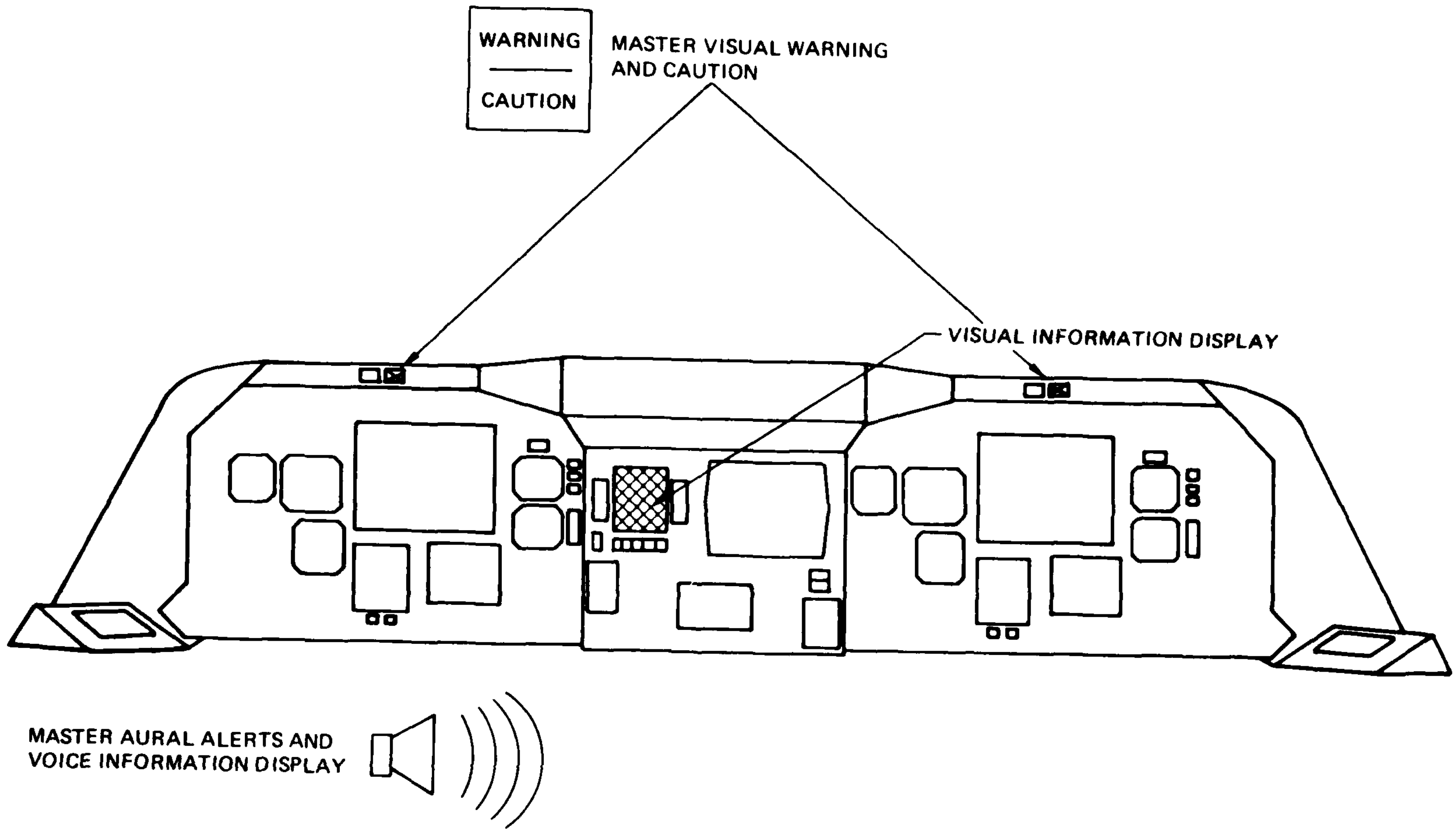


Figure 5.2.1-1. Advanced Alerting System

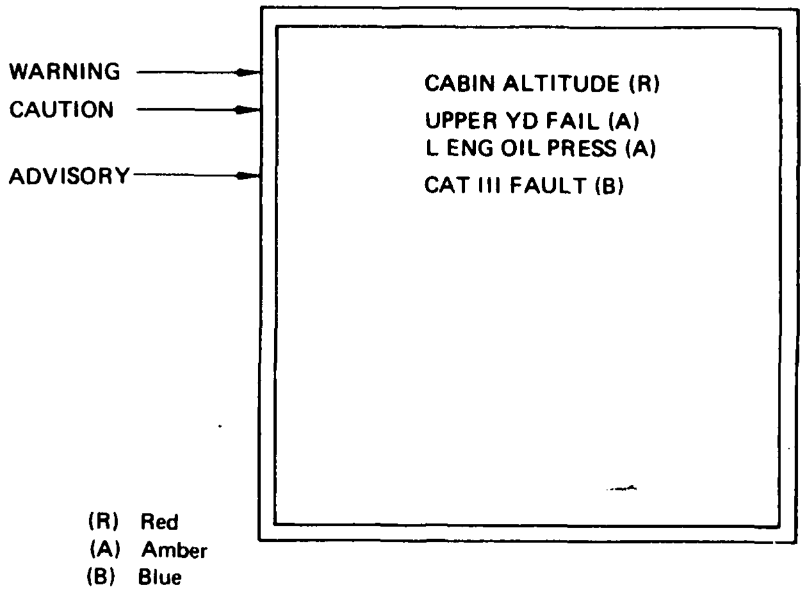


Figure 5.2.1-2. Typical Format for the Advanced Information Display

programmable information display. Figure 5.2.1-2 presents a typical format for the messages. The alphanumeric display used in the test was capable of presenting 12 lines of messages with 16 characters per line. Character size was 0.2 inch high by 0.1 inch wide; character separation was 0.08 inch, word separation was 0.26 inch or one letter space; and line separation was 0.05 inch. Warning messages were presented in red, cautions in amber, and advisories in blue. Each new alert message was surrounded by a flashing box of the same color to indicate that it was a new alert. The flash rate of the box was four times per second with equal times for "on" and "off". Since the Phase 1 testing had investigated the presentation of alerts with other messages already on the display, a duplication of that was not necessary; and the alert messages were presented on a blank display. Finally, a dedicated speaker was used for the master aural alerts and the voice messages. This speaker was located to the left of the pilot and separated by approximately 90^0 from the speaker used to present ATC communication. The sounds used for the master aural alerts were selected using two criteria. First, the sound

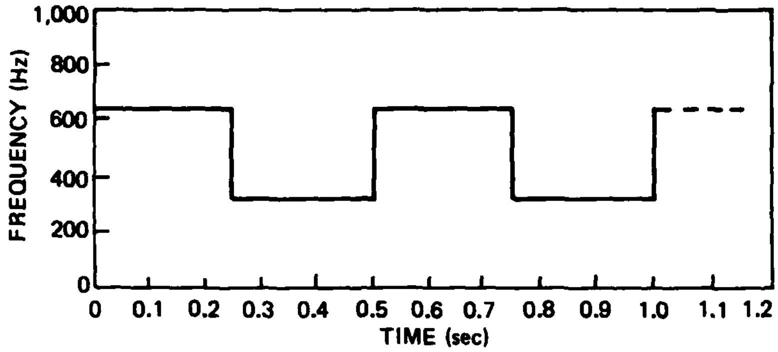
had to be unique and easily distinguishable; second, they should not convey any stereotypical meaning to the pilot, (e.g., bell = fire). To meet these requirements the following sounds were chosen:

Warning - A sound characterized as a European police car siren. This sound consisted of two tones (high, 660Hz and low, 330Hz) which alternated back and forth at a rate of two times a second. The shape of the sound is given in Figure 5.2.1-3.

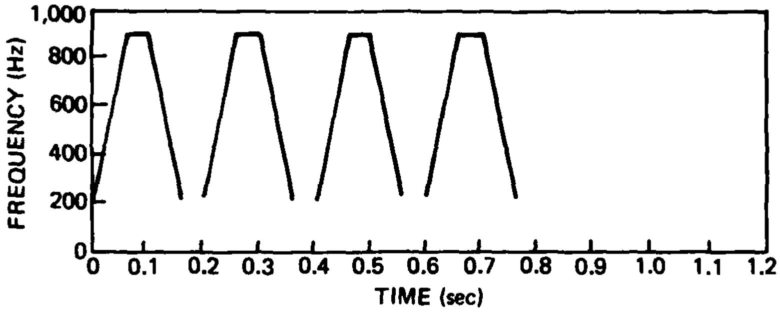
Caution - A short pulsing sound. The original intention was to choose a steady-state sound for caution alerts. It was determined, however, that the number of steady state sounds in present-day use was so large that the requirement for avoiding stereotypic sounds could not be met; therefore, a unique sound was developed for testing. The caution sound started at the low tone (200Hz) with a 60 msec rise to the high, (800Hz) a 40 msec presentation of the high, a 60 msec fall to the low, and a 40 msec silent time. Four such cycles were presented for the caution alert. The shape of the caution sound is shown in Figure 5.2.1-3.

Advisory- Single stroke chime. A 475Hz tone was presented for 2.0 sec with a 50 msec rise and a 1.8 sec fall in intensity. The shape of the sound is shown in Figure 5.2.1-3.

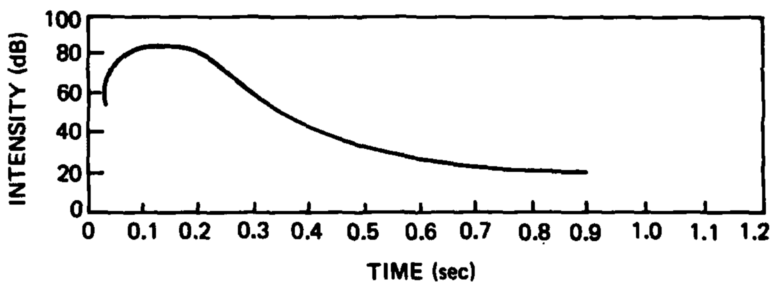
The peak intensity levels for the tones were adjusted to approximately 78 dB which was 8 dB above the average ambient noise in the simulator flight deck. Voice messages that occurred automatically (system A) were preceded by a 0.75 seconds presentation of the master warning/caution aural alerts. The voice message was then repeated until the pilot made the correct response or cancelled the alert. The off-time interval between repetitions was 0.2 seconds. Peak intensity levels for the voice were also held at approximately 78 dB. The voice messages for system B were not presented automatically but rather by pilot action. For this system, the warning and caution master aural alerts continued until the pilot selected the voice message, cancelled the aural alert manually or solved the problem. The voice message was presented only when the pilot initiated an action to hear it, and the message was presented once for each selection.



(a) Warning Intensity: 78 dB



(b) Caution Intensity: 78 dB



(c) Advisory Frequency: 475 Hz

Figure 5.2.1-3. Master Alerting Sounds

The flight engineer's station was also equipped with a programmable information display which presented the same messages that appeared on the pilot's display. The flight engineer also heard the same aural alerts as the pilot but did not have the ability to manually cancel them or to call for a repeat of voice messages. The location of the flight engineer's information display is shown in Figure 5.2.1-4.

Figure 5.2.1-5 illustrates the arrangement of the alerts in the conventional pilot system. As stated in Section 1.2, this baseline system was not designed to represent any specific existing aircraft but rather to be representative of those in present use. The warnings were presented by discrete annunciators (as can be seen from the position of the FIRE and GEAR lights in Figure 5.2.1-5); they were also accompanied by discrete tones (such as for CABIN ALTITUDE and OVERSPEED). All cautions illuminated the master caution light plus either a distributed light, (e.g., ALTITUDE or LE FLAPS) or a light on the annunciator panel. The ALTITUDE alert was also accompanied by a discrete tone. All advisories illuminated lights on the annunciator panel.

The discrete aural alerts were presented at an intensity of approximately 85 dB or the prescribed 15 dB above ambient noise.

The flight engineer's conventional alerting system also consisted of distributed alerts. Since the flight engineers station has no direct warning indicators, warnings were interpreted from the pilot's annunciations. Cautions and advisories were presented as lights on the active panels or on the annunciator panel. Figure 5.2.1-6 illustrates the location of the active system panels and the annunciator panel. The programmable information display was not operational for the conventional alerting system.

5.2.2 TIME-CRITICAL WARNING TEST

The basic test configuration for the time-critical warning test is shown in Figure 5.2.2-1. There were four independent variables for this test: a) display location, b) presentation format, c) voice format, and d) message content. The display location variable had two levels: within the pilots primary field of view (15^0) or within the pilot's secondary field of view

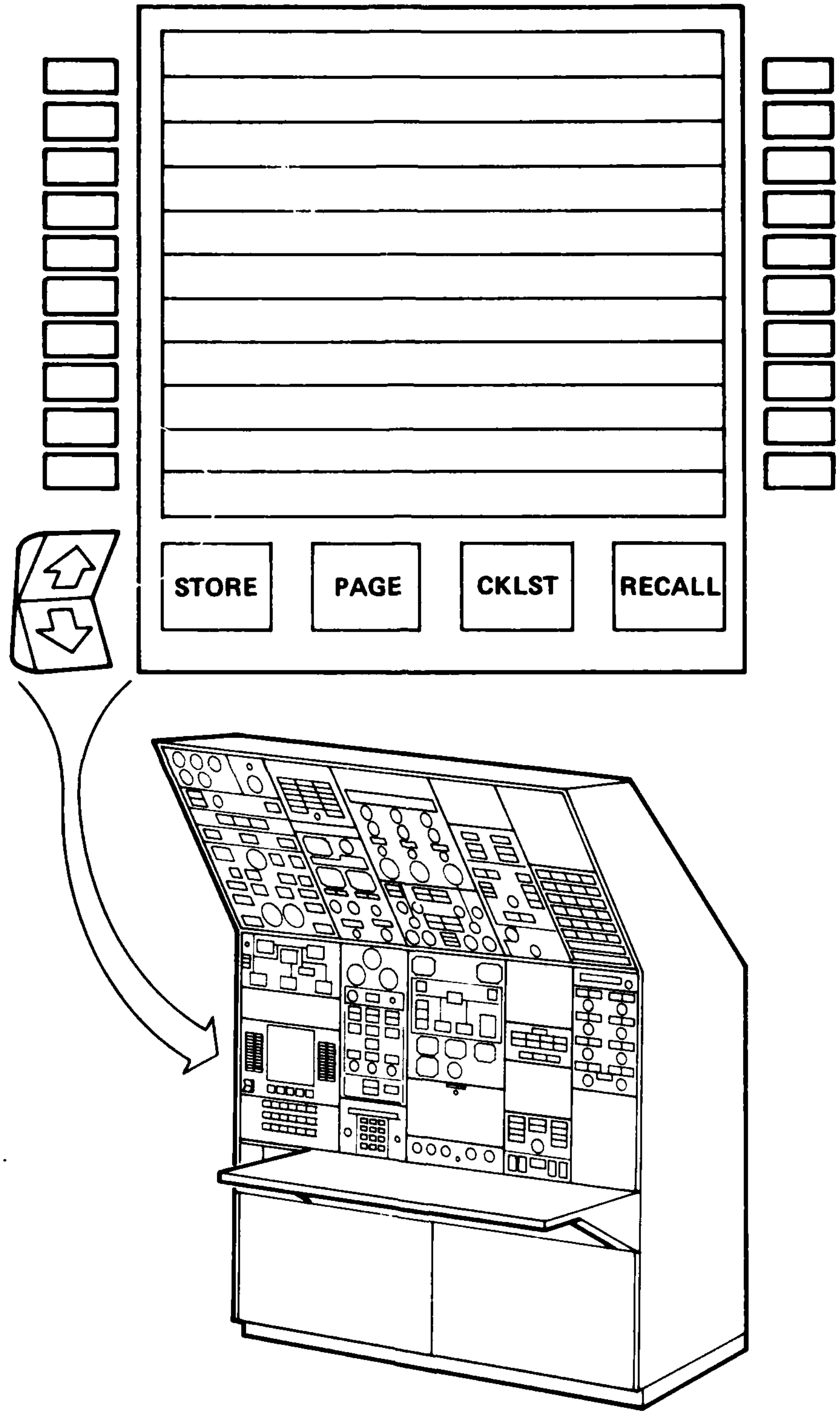


Figure 5.2.1-4. Flight Engineer Advanced Warning and Caution Display

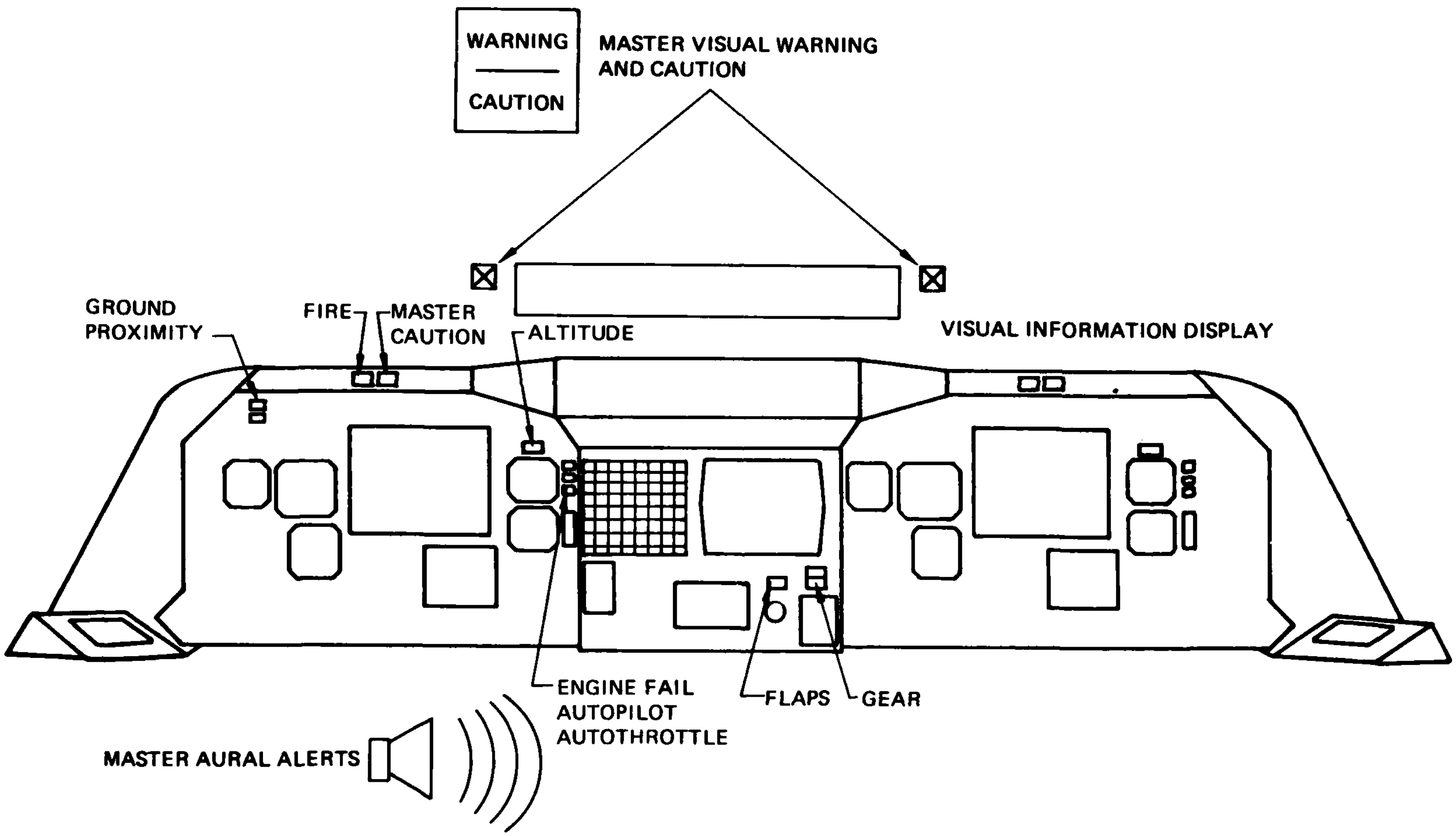


Figure 5.2.1-5. Conventional Alerting System

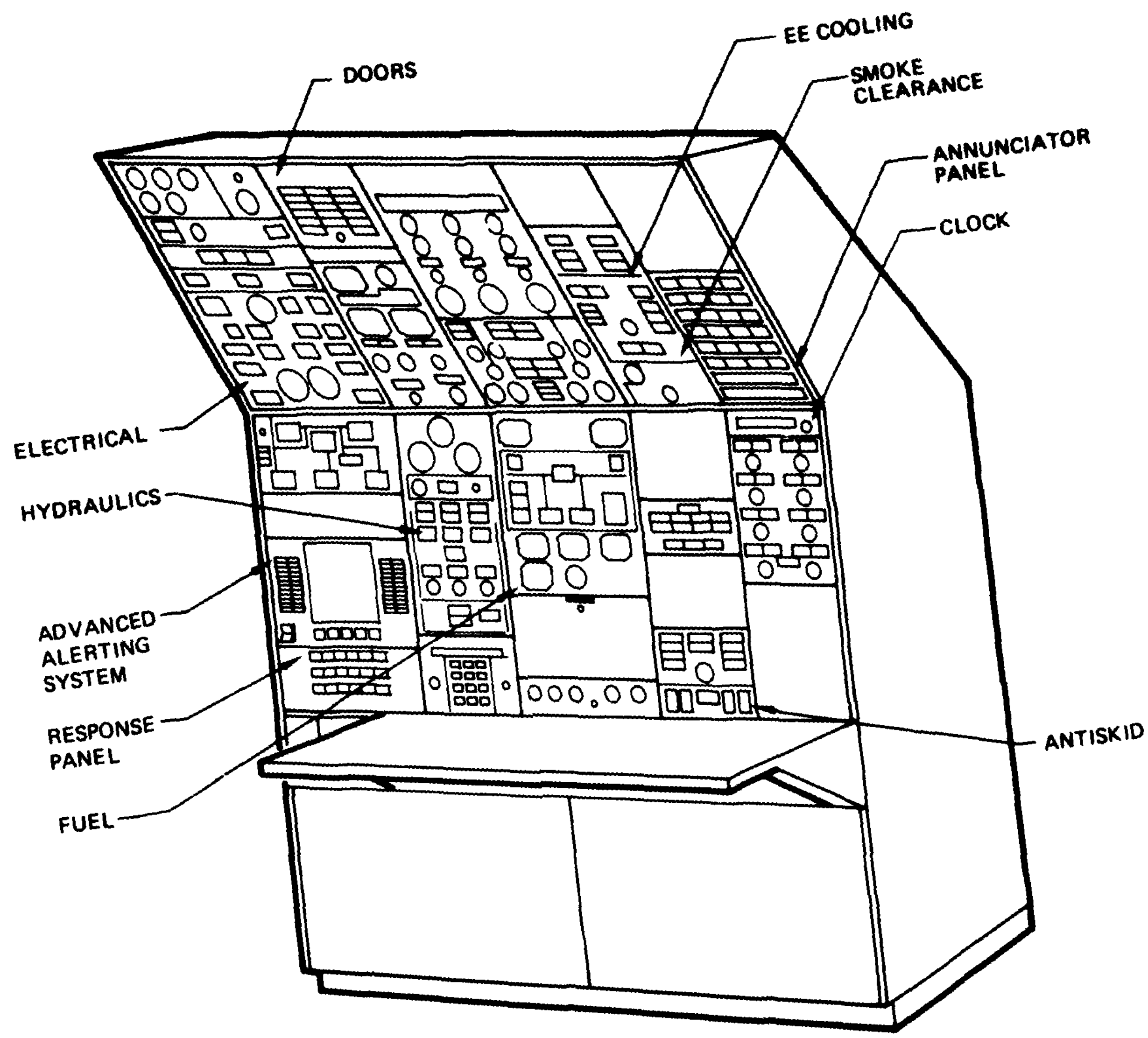


Figure 5.2.1-6. Flight Engineer Station Active System Panels

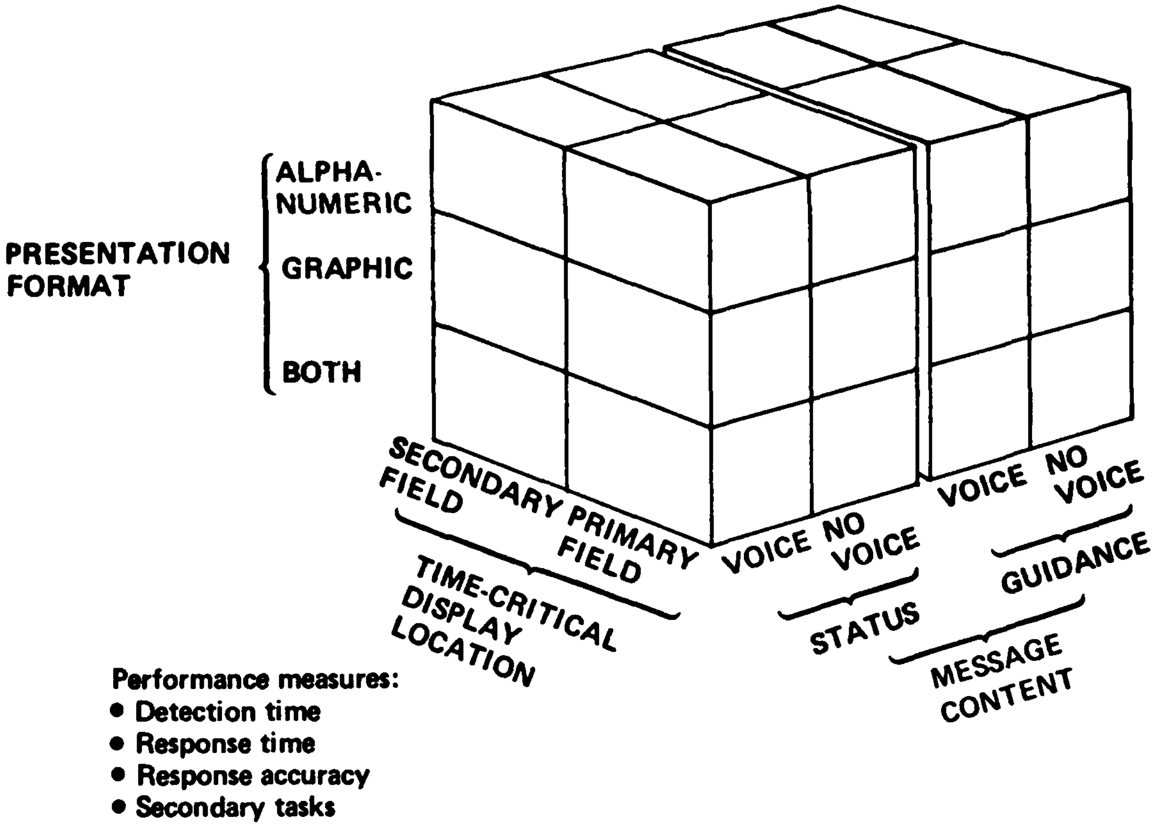


Figure 5.2.2-1. Test Configuration For The Time-Critical Warning Tests

(30^{0}). The presentation format variable had three levels: alphanumeric messages, graphic messages and a combination of alphanumeric and graphic messages. The voice format variable had two levels: the presence or the absence of voice alerts. The message content variable had two levels: the messages provided the pilot with status information, (e.g., TERRAIN), or gave the pilot guidance as to the correct action, (e.g., PULL UP). Thus, the 24 cells shown in Figure 5.2.2-1 represent a 2 x 3 x 2 x 2 factorial analysis of variance design. A mixed model design was used with repeated measures on the first three variables since all subjects received all treatments. However, the subjects were nested within the levels of message content since each had only one content. Figure 5.2.2-2 illustrates the locations of the information display in the central panel and the display located in front of the pilot

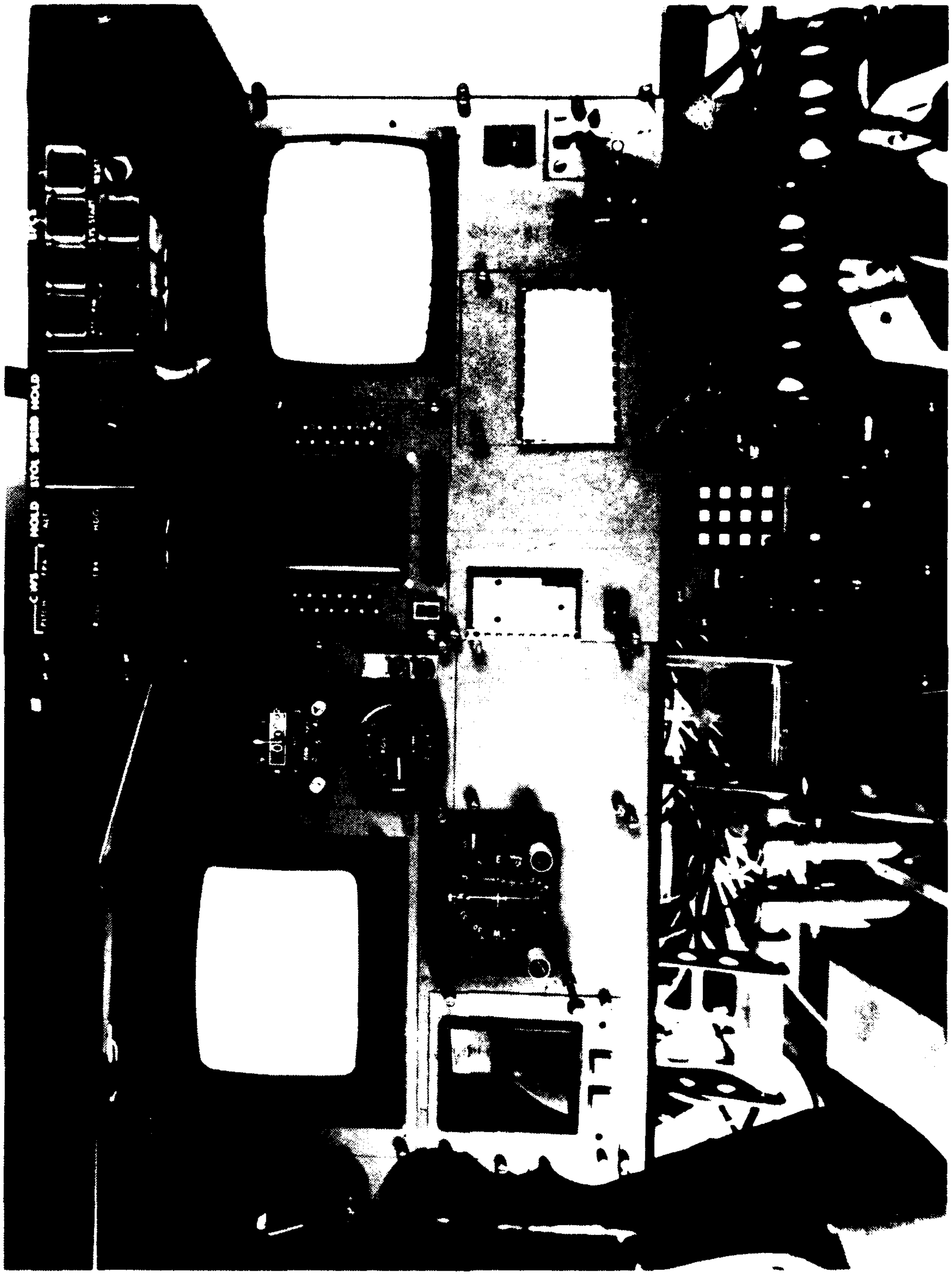


Figure 5.2.2-2. Time Critical Display Location

(30° field of view and 15° field of view, respectively). The figure also shows the location of the master visual alert with respect to the two programmable display locations. The top 1.5 inches of each of programmable display was used to present time-critical warnings. The bottom 3 inches of the centrally located display was used as the alerting system information display and presented all alerts. The center display was therefore capable of presenting the time-critical warnings and eight lines of alphanumeric information with 16 characters per line. Figure 5.2.2-3 presents a typical display format. The display in front of the pilot only presented time-critical warnings.

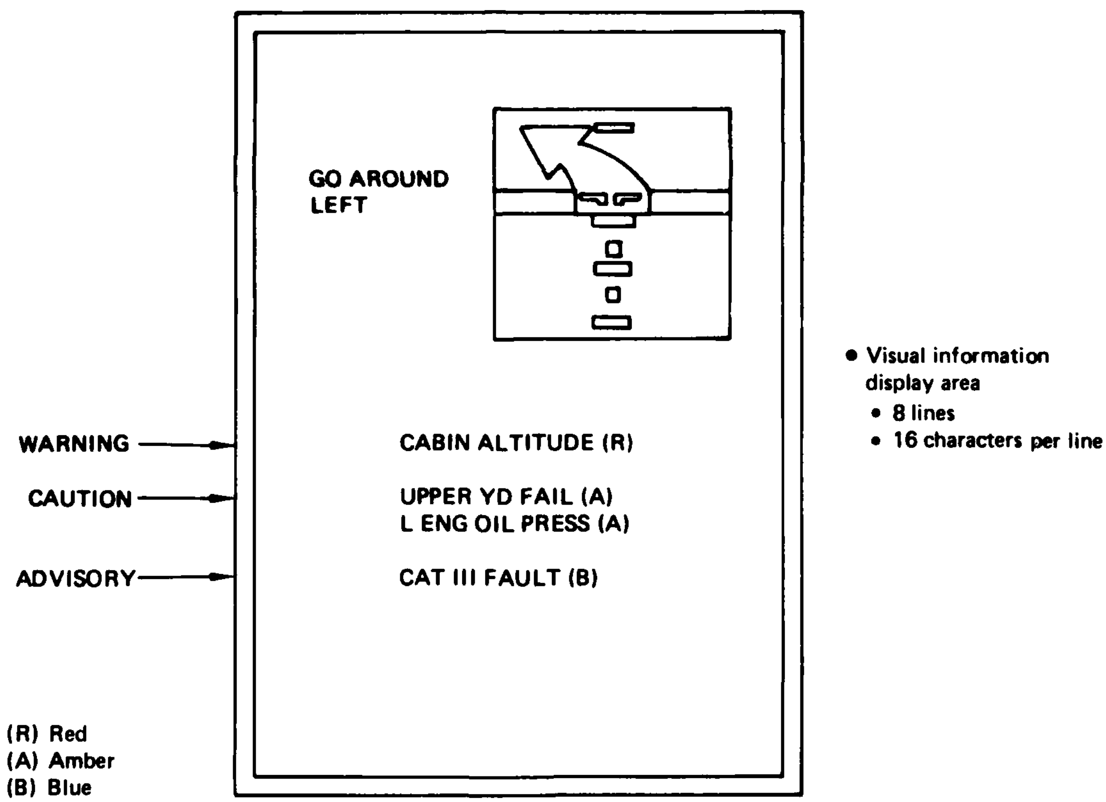


Figure 5.2.2-3. Typical Time-Critical Test Display Format

To evaluate the media for presenting time-critical warnings it was necessary to compare them only with other warnings; therefore, all alerts in this test, except for multiple alerts, were warnings (red). Since the Phase 1 testing investigated the presentation of alerts with other messages already on the screen, a duplication of that test was not necessary, and the alert messages appeared on a blank screen.

Both the master aural alerts and the voice messages were presented on a speaker located to the left of the pilot. The intensity of the alerts was set at 78dB or approximately 8dB above the average ambient noise.

The rationale for selecting the display locations, presentation format, voice format and message format variables was as follows:

All variables were chosen to satisfy the underlying requirement to elicit a quick and accurate response from the pilot. Each variable had as a basis some facet of the advanced alerting concepts. The centralized display location within the pilot's secondary field of view (within 30° of the centerline of vision) was shown in Phase 1 to be adequate when combined with a master attention-getting alert. However, moving the information into the primary field of view (15°) for a certain set of warnings decreased the pilot's response time to those messages.

The second variable investigated was the presentation format. The programmable information display presented the pilot with alphanumeric alert messages. This required the pilot to read the message, understand its content, decide a course of action and, finally, respond. This sequence and the time it takes is appropriate for most alerts. However, if time is a critical factor it may be possible to reduce the overall time from alert onset to pilot response by providing a graphic representation of the alert to facilitate interpretation, or by combining graphic with alphanumeric information. In conjunction with the presentation format, the third variable message content may also be used to reduce the time from alert to response. The normal method of alert presentation is to give the pilot the status of his aircraft, e.g., "LEFT ENGINE FIRE" or "OVERSPEED". This requires the pilot to follow the above sequence remembering the appropriate response and executing

it correctly. An alternative content for time-critical messages would be to give the pilot guidance by providing the correct course of action which should accelerate the response and decrease the probability of error. To eliminate the possibility of negative transfer between the status and guidance message formats, half of the pilots were given status messages and half, guidance. The alphanumeric and graphic presentation used for both status and guidance messages are shown in Figure 5.2.2-4.

The final variable investigated was the value of the voice message. Although it has been shown that voice messages have the potential to significantly interfere with other voice communications in the flight deck, the severity and time-criticality of some warnings may make a chance of voice alert interference appropriate. The question remains whether or not the voice alert changes crew response time or performance accuracy in any way.

5.3 PILOT SAMPLE FOR THE SYSTEM TESTS

Fourteen pilots with a wide range of experience, including line pilots, instructors, and management pilots, participated in the Phase 3 tests at the Boeing facility. The group consisted of representatives from the three contractor companies, Boeing, Lockheed and McDonnell Douglas, and from the airlines including American, Eastern, Northwest, SAS, TWA, United, and Western. A summary of the pilot experience is presented in Table 5.3-1; numerical entries on the right hand side of the table indicate the specific experience by aircraft type and recency of the experience (A is most recent).

5.4 CREW TASKS

5.4.1 FLIGHT TASK

To simulate the flight deck environment and work pattern, the pilots performed test flights of 31 minutes duration in the simulator. A realistic aircraft model was used for the basic flying task; the pilots were required to fly a prescribed flight plan, respond to ATC communications, locate targets in an external visual scene and to respond to alerts. The flight instrumentation available to the pilots to perform their tasks, shown in

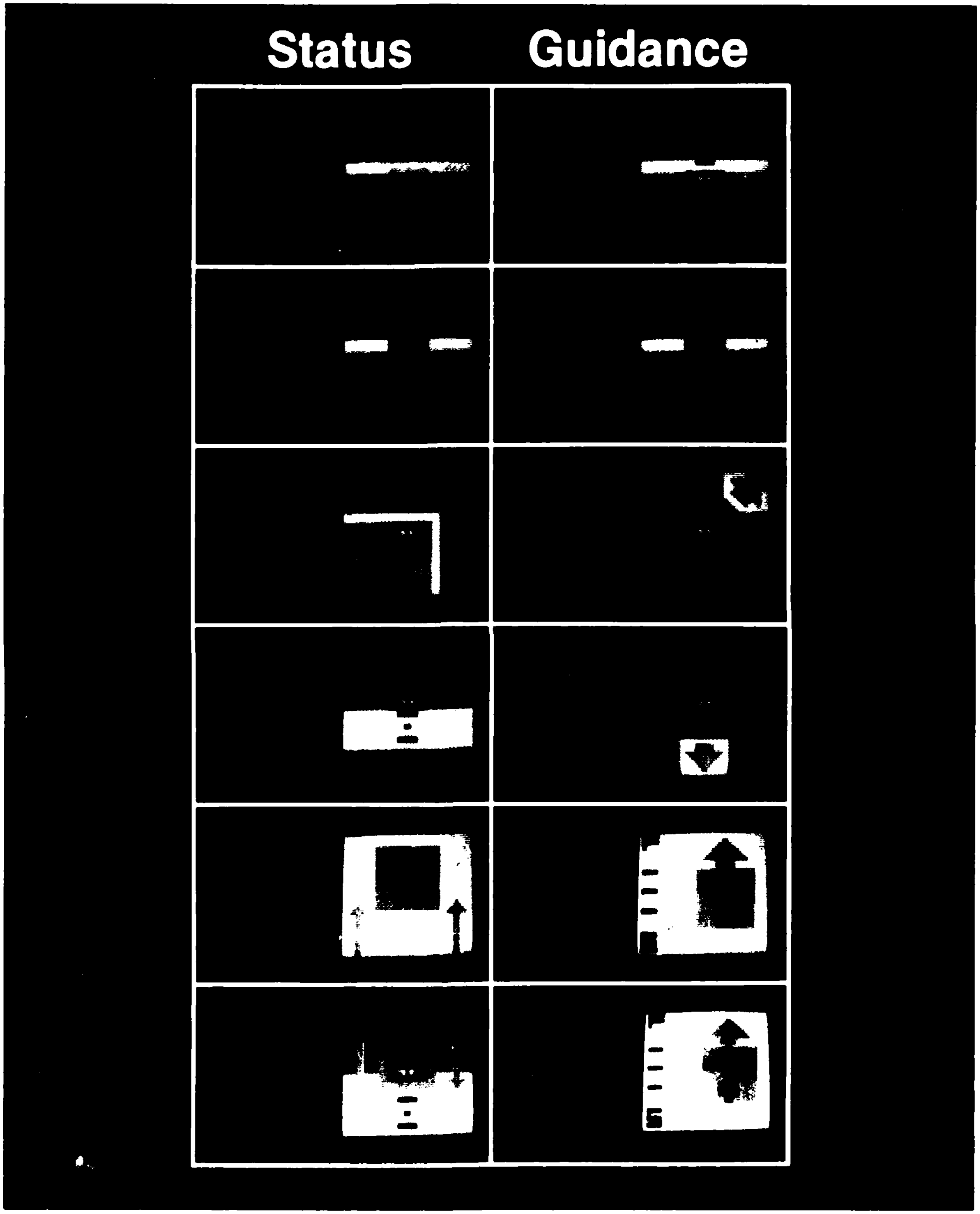


Figure 5.2.2-4. Time-Critical Warning Display Formats

Statistic	Pilot experience			Specific aircraft experience								
	Age	Years flying	Flight-hours (1,000)	Recency*	707	727	737	747	DC-8	DC-9	DC-10	L-1011
Mean	46.8	27.2	13.6	A	2	6		2		1	3	1
Standard deviation	9.5	9.1	7.8	B	1		4		1	4	1	1
Range	27 to 67	10 to 42	5.5 to 35.0	C	2	2			1	1		
				D	3				1			

*A is the most recent aircraft flown.

Table 5.3-1. Summary of Pilot Experience

Figure 5.4.1-1, consisted of an airspeed indicator; an electronic altitude direction indicator (EADI-roll, pitch, glideslope); an altimeter; a rate of climb indicator; a horizontal situation indicator (HSI-course, DME, localizer); the pilot's time-critical display; and a clock to indicate flight time. The center panel contained the visual information display, the electronic engine instrument display, flaps indicator and gear lights.

The flight controls available to the pilot included: wheel and column with trim; rudder and toe brakes; speed brakes; flap handle; gear handle; fire handles; throttle; response key matrix and a 12 key input panel.

The test flight plan is illustrated in Figure 5.4.1-2. It was divided into five flight phases, takeoff, climb, cruise, descent and landing. The pilot performed a visual takeoff (Figure 5.4.1-3) on a heading of 360^{0} at a rate of climb resulting from IAS of 210 Kts. The outside visual scene disappeared after takeoff. To achieve a more controlled flight path for the flights, the auto throttle was engaged at 2000 feet and flew the prescribed speed profile for the remainder of the flight. The pilot leveled off and held 15000 feet through turns 1, 2 and 3. At a point 10 miles from waypoint D he received an ATC clearance to descend to 10,000 feet. After executing turn 4 ATC cleared the aircraft to 4000 feet and instructed the pilot to hold that altitude until crossing the mountain 9.5 miles from the runway. At 18 miles out, the outside

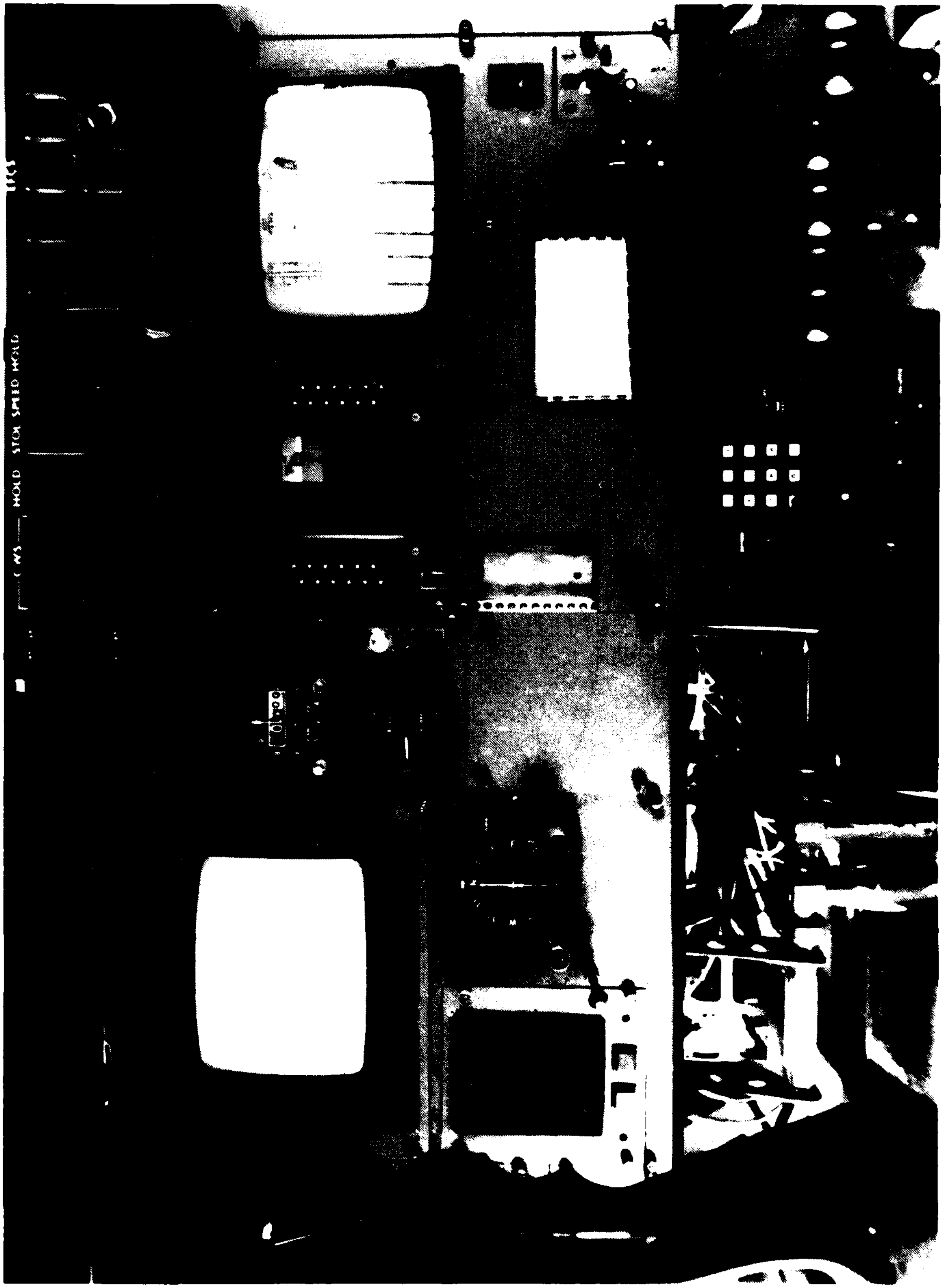


Figure 5.4.1 1. Flight Deck

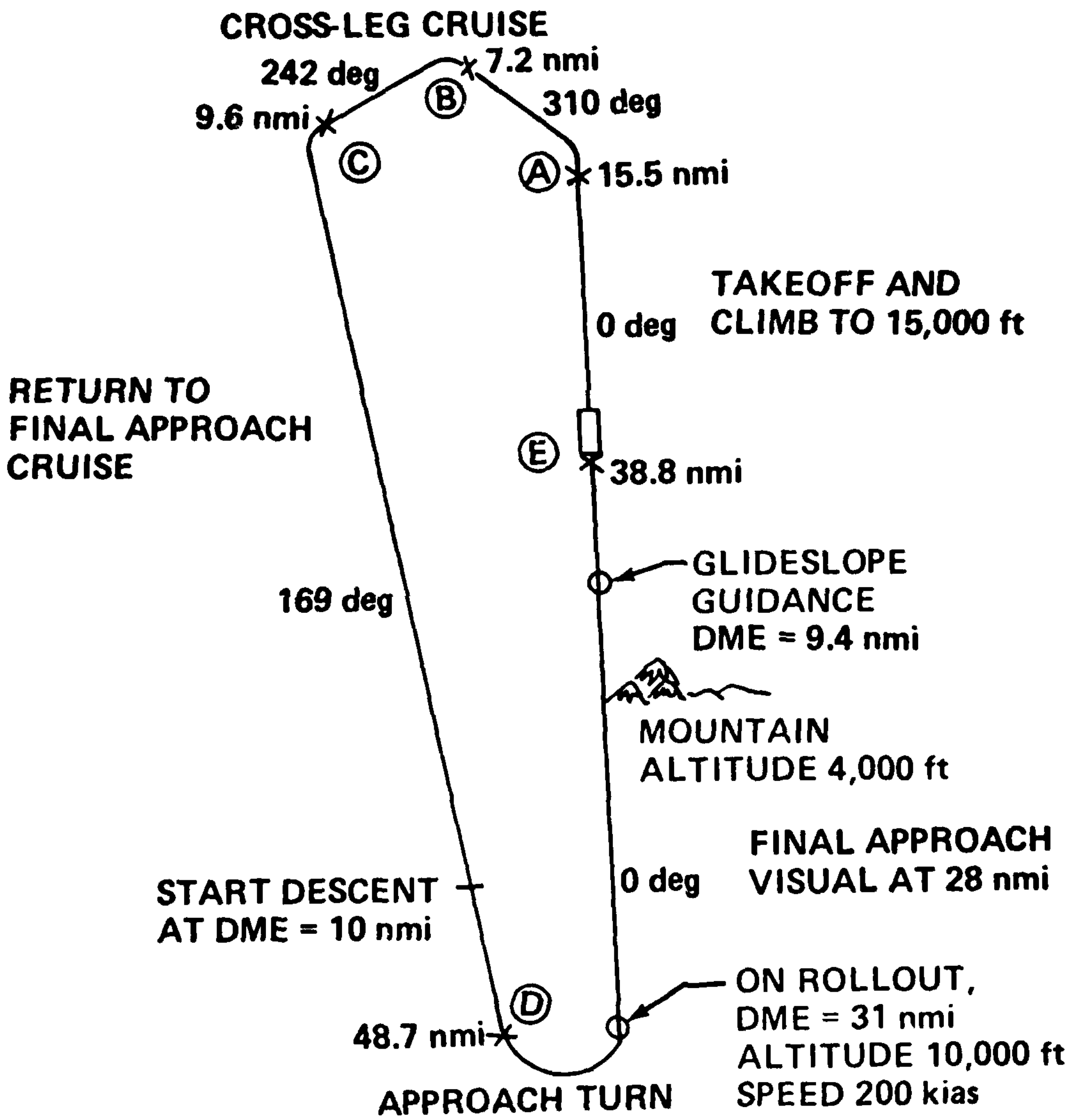


Figure 5.4.1-2. Phase III Flight Path

Figure 5.4.1-3. Visual Flight Takeoff

visual scene again became active for the approach. At 9.5 miles he was further cleared for ILS approach and landing. The glideslope raw data box appeared on the EADI, and the visual approach continued, until 3 miles and 1000 feet at which point the visual scene again disappeared to enable the outside camera to switch from one terrain board to another. At one mile and 350 feet the visual scene was again presented for landing. The ATC clearances associated with the flight plan are presented in Table 5.4.1-1.

5.4.2 TARGET RECOGNITION

To assure that the pilots spent some of their time looking outside the cab at times other than takeoff and landing, an outside visual task was developed. Occasionally during each flight, ATC would request the pilot to report traffic location (Boeing 101, say current traffic location). The traffic was simulated by using groups of split rings all of which were oriented in the same direction except for one target ring (see Figure 5.4.2-1). The pilot's task was to search three groups of rings, find the single target ring, and report its position. Reports were made by inputting the target location in a prescribed manner through the 12-key keyboard. This task was reported by some of the pilots to be very comparable to an actual in-flight traffic search except that in actual flight ATC would normally give them some idea where the traffic was, e.g., "Boeing 101 you have traffic at two o'clock". Therefore, the test task was possibly a little more difficult than real world traffic identification. Figure 5.4.2-2 shows the correct target screen/quadrant number for each slide set used in the study.

5.4.3 FLIGHT ENGINEER'S FLIGHT TASK

The work pattern and task loading of the flight engineer was very difficult to simulate, the flight engineer generally has a higher loading at the beginning and end of each flight and is somewhat unloaded during the middle portion. However, if a problem occurs there may be a dramatic increase in workload. To simulate worst-case, or near worst-case, the workload for the test flight was artificially high.

Table 5.4.1-1. ATC Communication

	Distance	Altitude	ATC
1	0	0	Boeing 101: Pinevalley Tower: cleared for takeoff runway 36, wind calm altimeter 29.92. Cleared left heading 310 deg at fix ALPHA, Monitor Pinevalley Approach Control 348.2 after takeoff.
2	8 nmi	9,000	Boeing 101: Pinevalley Approach Control: say current traffic location.
3	21.7 nmi	15,000	Boeing 101: Pinevalley Approach Control: fix BRAVO turn left heading 242 maintain 15,000.
4	29.3 nmi	15,000	Boeing 101: Pinevalley Approach Control: fix COCOA, turn left heading 169 maintain 15,000.
5	44.3 nmi	15,000	Boeing 101: Pinevalley Approach Control: say current traffic location
6	56.3 nmi	15,000	Boeing 101: Pinevalley Approach Control: say current traffic location
7	71 nmi	15,000	Boeing 101: Pinevalley Approach Control: descend to 10,000, cleared penetration and ILS approach runway 36
8	72.5 nmi	14,300	Boeing 101: Pinevalley Approach Control: say current traffic location
9	90.8 nmi	10,000	Boeing 101: Pinevalley Approach Control: have you starting approach, do not descent below 4,000 feet until DME 9.5 nmi, current winds light and variable altimeter 29.92, monitor Pinevalley Tower 253.8
10	112.3 nmi	4,000	Boeing 101: Pinevalley Tower: cleared to land runway 36

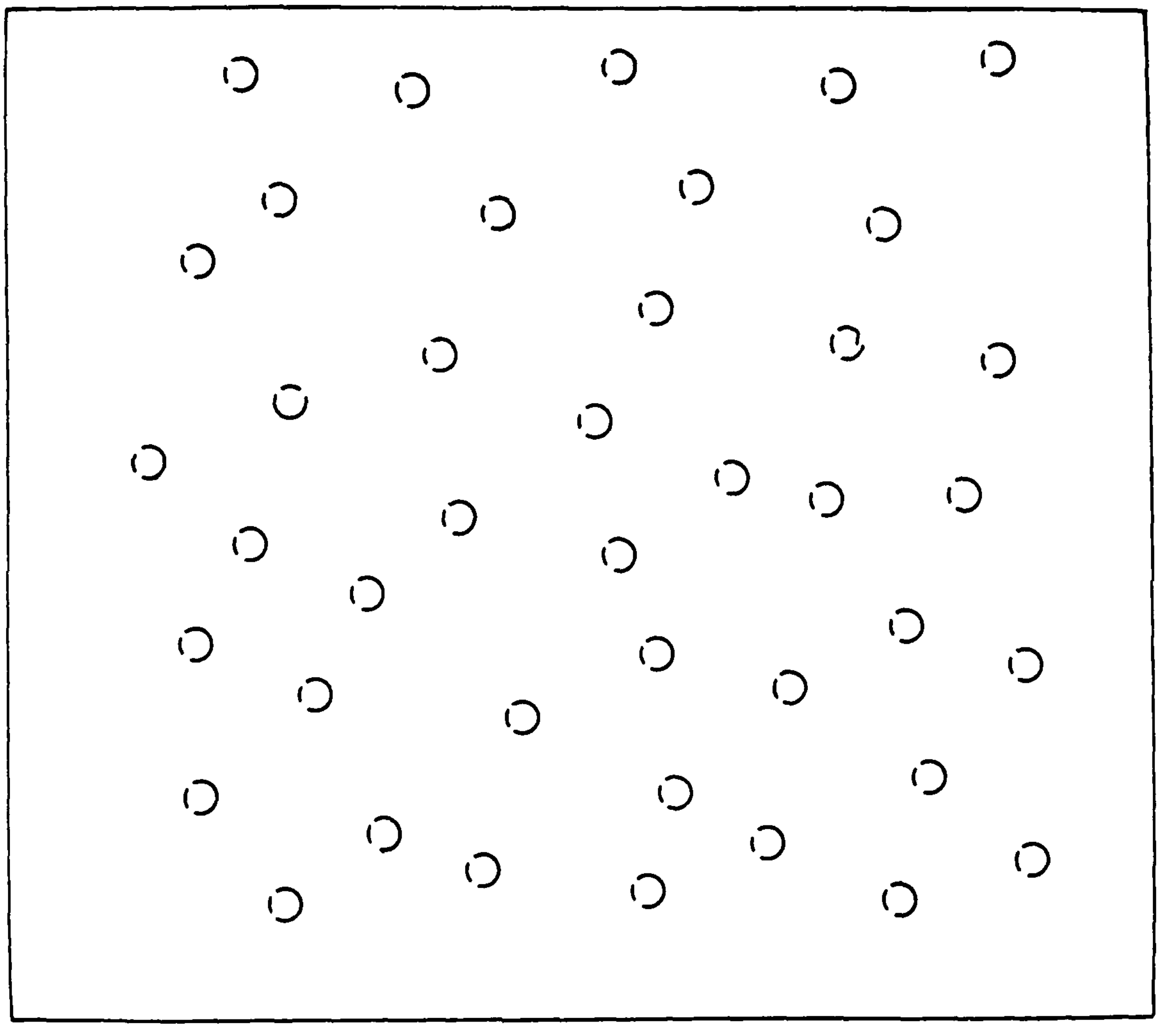
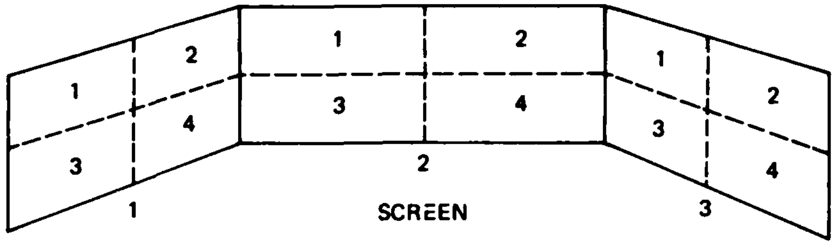


Figure 5.4.2-1. Outside Visual Search Task



Slide set	Target		Slide set	Target		Slide set	Target	
	Screen	Quadrant		Screen	Quadrant		Screen	Quadrant
1	1	4	25	3	3	49	3	3
2	3	1	26	1	4	50	1	4
3	2	3	27	3	1	51	3	1
4	1	1	28	2	4	52	2	4
5	2	4	29	1	1	53	1	1
6	3	1	30	3	3	54	3	3
7	1	4	31	3	1	55	3	1
8	2	3	32	2	4	56	2	4
9	2	2	33	2	2	57	1	4
10	1	1	34	1	1	58	3	1
11	3	1	35	3	1	59	2	4
12	3	4	36	3	4	60	1	1
13	2	2	37	2	2	61	2	4
14	1	1	38	1	1	62	3	1
15	3	3	39	3	3	63	1	4
16	2	3	40	2	3	64	2	3
17	2	2	41	2	2			
18	3	4	42	3	4			
19	2	1	43	2	1			
20	1	4	44	1	4			
21	2	1	45	2	1			
22	3	2	46	3	2			
23	1	2	47	1	2			
24	3	4	48	3	4			

Figure 5.4.2-2. Answer Sheet for Slide Sets

The flight engineer flew at the same time as a pilot. Their tasks consisted of reading instruments, logging problems or faults and their time of occurrence, and locating the outside visual targets. The instrumentation that was functional at the flight engineer's station is illustrated in Figures 5.4.3-1, and -2. The electrical and hydraulic systems had round dial instruments, and the three round dial indicators on the hydraulic system panel were switchable to provide readings for each of the three hydraulic systems (left, center and right); they therefore represented 9 dial instruments. The electrical and fuel instruments were not switchable.

At certain predetermined intervals (10 times during each flight), the reading on one of the instruments would drop; the flight engineer's task was to detect the low reading and log the time of occurrence. The task required the flight engineer to scan the instruments during the flight as well as to search for and identify the outside visual targets. The flight engineers were also required to log all system alerts after they had responded to them.

5.4.4 ALERT RESPONSE TASKS

When the pilots detected an alert, they were required to depress a button located on the left side of the control wheel. This action was used to mark the time that the pilot perceived the new alert. After identifying the specific alert, the pilot performed a prescribed response to solve the problem. Table 5.4.4-1 presents the operational or system conditions that were used, along with their associated responses. As can be seen, the responses were divided between two categories, those that were made with operable system elements (e.g., wheel back, cycle gear, etc) and those that were made through a response panel by depressing the switch corresponding to the system which had a problem (e.g., L SYS HYD PRSR, ANTI-ICE). The response panel had 18 switches located in the center aisle stand, and configured as seen in Figure 5.4.4-1. Caution and advisory level alerts were always responded to through this panel. When the pilot made the correct response, the alert message was removed from the screen, the master visual alert was extinguished and the aural alerts were silenced.

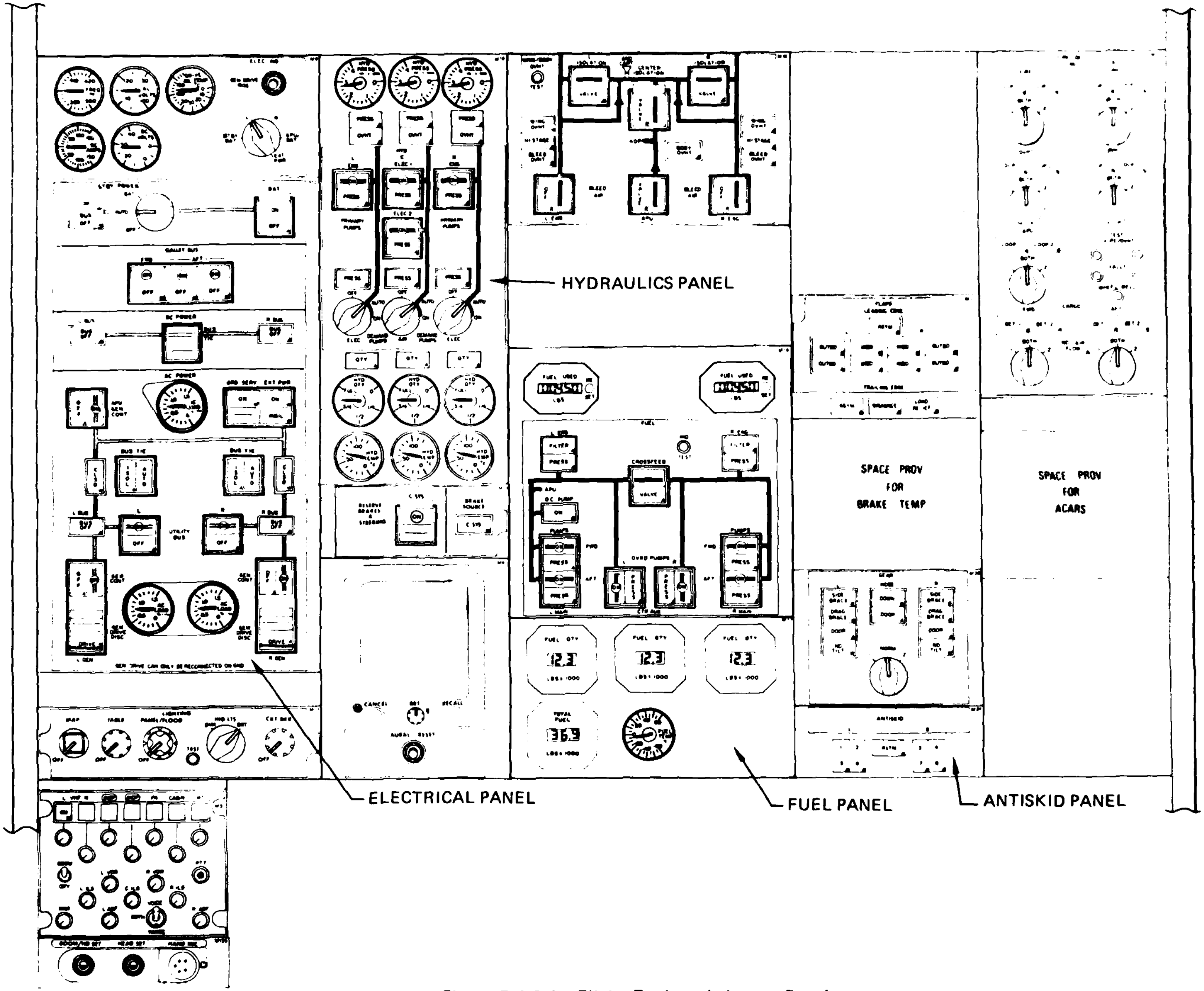


Figure 5.4.3-1. Flight Engineer's Lower Panel

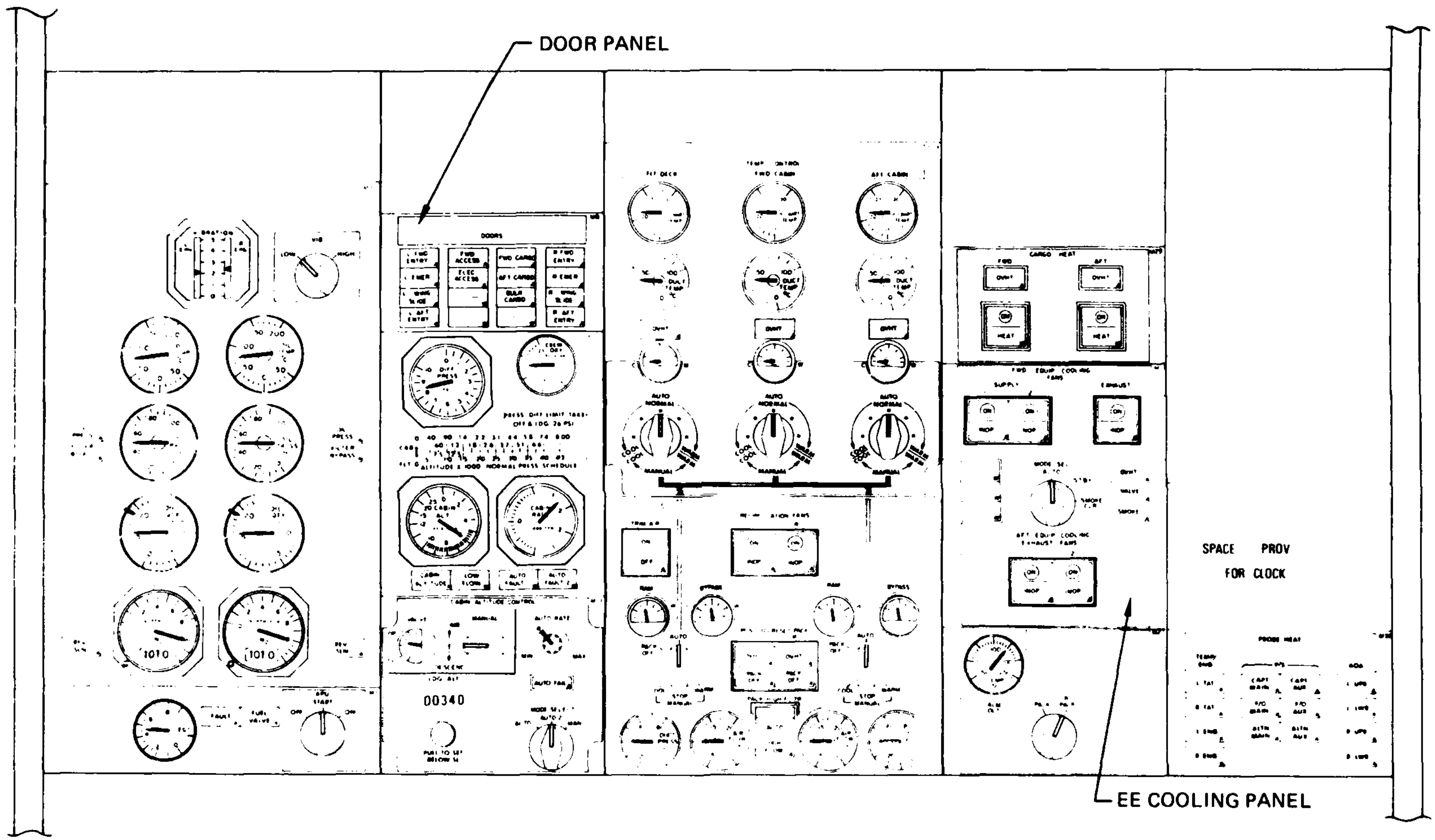


Figure 5.4.3-2. Flight Engineer's Upper Panel

ANTI ICE	BRK	ENG/APU STATUS	AUTO SPLR	ANTI SKID	DOOR
ELEC	HYD	FUEL	ECS	GEAR	FIRE
OVRSPD	CABN CALL	SELCAL	FLT CONTRL	ALT ALRT	A/T

Figure 5.4.4-1 Pilot's Response Panel

GND PROX 45	FIRE 46	A/T 47	FLT CONTRL 48	ENG STATUS 49	GEAR 50
OVRSPD 51	CABN ALT 52	CONFIG 53	ANTI SKID 54	ECS 55	DOOR 56
ANTI ICE 57	AUTO SPLR 58	ALT 59	BRK 60	CABN CALL 61	SELCAL 62

Figure 5.4.4-2 Flight Engineer's Response Panel

The flight engineers' response to alerts was not the same as the pilots as they were not required to signal detection before responding. Their responses were also divided into two categories based on operable systems but the distinction was not as clear cut. Warnings always required a response panel input (see Figure 5.4.4-2 for the flight engineer's response panel), while caution and advisory level alerts could be responded to either on the appropriate system panel or on the response panel depending on the specific alert. Table 5.4.4-1 presents the flight engineer response for each alert.

5.5 TEST PROCEDURES

5.5.1 SYSTEM VALIDATION TESTS

The variables tested in the svstem validation tests are described in section 5.2.1. All variables not tested were held constant or controlled to avoid biasing or confounding the results. Simulated aircraft ambient noise with an average intensity of approximately 70 dB was presented during the flight task to mask the uncontrolled noise that may have been occurring around the cab. This noise was controlled by throttle position and air speed to provide a realistic sound spectrum based on aircraft performance. During each flight, variations of the noise level were kept within the range of 67dB to 72dB. The ambient light levels were kept very low (5 ft-L) to permit the use of the outside visual scene. ATC communications were presented at 75dB and held constant for all trials; visual message constrast was also held constant for all trials. All pilots received the same instructions to minimize experimenter bias (see Appendix F).

Table 5.4.4-1. Operational and System Conditions for Alerts and Their Associated Response

Alert	Alert code	CRT message	Urgency level **	Pilot's response	Flight engineer's response
Ground proximity	1	GROUND PROX	W	COLUMN BACK	–
Thrust reserves too low	2	THR RSV TOO LOW	W	THROTTLE FORWARD	–
Collision avoidance	3	COLLISN ABOVE	W	COLUMN FORWARD	–
Collision avoidance	4	COLLISN LOW LEFT	W	COLUMN BACK WHEEL RIGHT	–
Tailwind shear	5	TAILWIND SHR	W	THROTTLE FORWARD	–
Downdraft shear	6	DOWNDRAFT SHR	W	THROTTLE FORWARD	–
Left engine fire	8	L ENG FIRE	W	PULL LEFT FIRE HANDLE	RP FIRE*
APU fire	9	APU FIRE	W	PULL CENTER FIRE HANDLE	RP FIRE
Flaps set improperly	10	TAKEOFF FLAPS	W	CYCLE FLAP HANDLE	RP CONFIG
Flaps set improperly	15	LANDING FLAPS	W	CYCLE FLAP HANDLE	RP CONFIG
Right engine failure	11	R ENG FAIL	W	RP ENG STATUS	RP ENG STATUS
Gear not down	12	GEAR NOT DOWN	W	CYCLE GEAR HANDLE	RP GEAR
Overspeed	13	OVERSPEED	W	THROTTLE BACK	RP OVRSPD
Cabin altitude	14	CABIN ALT	W	COLUMN FORWARD	RP CABN ALT
Left generator drive oil	16	GEN DRIVE OIL	C	RP ELEC	DISCONNECT GENERATOR
Gear disagree	17	GEAR DISAGREE	C	RP GEAR	RP GEAR
Right system hydraulic pressure	18	R SYS HYD PRSR	C	RP HYD	CYCLE RIGHT HYDRAULIC SYSTEM
Antiskid inoperative	19	ANTI-SKID INOP	C	RP ANTI-SKID	RP ANTI-SKID
Left air-conditioning pack trip off	20	L PACK TRIP	C	RP ECS	RP ECS
Forward main door open	21	FWD MAIN DOOR	C	RP DOOR	RP DOOR
Right engine oil pressure low	22	R ENG OIL PRSR	C	RP ENG STATUS	RP ENG STATUS
Anti-ice inoperative	23	ANTI-ICE	C	RP ANTI-ICE	RP ANTI-ICE
Autospoiler inoperative	24	AUTO-SPOILER	C	RP AUTO-SPLR	–
Altitude alert	25	ALTITUDE	C	RP ALT	RP ALT ALRT
Left bleed off	26	L BLEED OFF	A	RP ECS	RP ECS
Galley bus off	27	GLY BUS OFF	A	RP ELEC	CYCLE SWITCH
Utility bus off	28	UTIL BUS OFF	A	RP ELEC	CYCLE SWITCH
Right engine hydraulic pump	29	R ENG HYD PUMP	A	RP HYD	CYCLE SWITCH
Left engine fire detector	30	L ENG FIRE DET	A	RP FIRE	RP FIRE
Left brake overheat	31	L BRAKE OVHT	A	RP BRK	RP BRK
Right forward fuel pump	32	R FWD FUEL PUMP	A	RP FUEL	CYCLE SWITCH
Forward cabin call	33	FWD CABIN CALL	A	RP CABN CALL	RP CABN CALL
SELCAL	34	SELCAL	A	RP SELCAL	RP SELCAL

* RP = response panel.
** W = warning   C = caution   A = advisory

Table 5.4.4-1. Operational and System Condition for Alerts and Their Associated Responses (Concluded)

Alert	Alert code	CRT message	Urgency level	Pilot's response	Flight engineer's response
Upper yaw damper failure	35	UPPER YD FAIL	C	RP FLT CONTRL	RP FLT CONTRL
Leading edge flaps	36	LE FLAPS	C	RP FLT CONTRL	RP FLT CONTRL
Air-conditioning pressure	37	AIRCOND/PRSR	C	RP ECS	RP ECS
Left generator off	38	L GEN OFF	A	RP ELEC	CYCLE SWITCH
Left bus tie	39	L BUS TIE	A	RP ELEC	CYCLE SWITCH
Right electric hydraulic pump	41	R ELEC HYD PUMP	A	RP HYD	CYCLE SWITCH
Autothrottle disconnect	43	A/T DISC	C	RP A/T	RP A/T

Each test flight was 31 minutes in length and contained nine alerts, three from each urgency level (warning, caution, advisory). The alerts were presented on a schedule of three minute intervals; however, to prevent the pilot's anticipation of the alerts, a 150 second interval around each three minute mark was allocated for the alerts (mark $\pm$ 75 seconds random). The alerts could therefore be presented as close together as 30 seconds. The times were chosen at random, and 10 different time scenarios were developed. The only restriction on the time selection was that no alert could occur after 30 minutes and 30 seconds into the flight to permit the pilot at least 30 seconds to respond to the last alert. To reduce the possibility of influencing the data by the order in which the alerts were presented, 10 random alert orderings were developed and combined at random with the time scenarios to produce the test scenarios.

Whenever task performance is measured under several different treatment conditions over an extended period of time, learning or fatigue may affect performance on later trials. Care was taken to design an appropriate counterbalancing scheme to prevent carry-over effects from differentiallv

affecting the performance measures for the different treatment conditions. It should be noted, therefore, that the order in which the pilot received the experimental treatments was also randomly assigned to prevent order bias from confounding the results (see Table 5.5.1-1). Immediately prior to each flight the pilot was briefed on the alerting system configuration that he would be using.

The daily test schedule for both the system validation tests and the time-critical tests is presented in Table 5.5.1-2; all pilots were to fly both tests. Two pilots were tested each week spending two and a half days per pilot in the simulation. The pilots overlapped on the afternoon of day three; this was the time when the flight engineer system validation tests were run. A total of 12 pilots completed the full test and 2 pilots completed just the system validation.

The test participation began with an introduction to the Visual Flight Simulation Facility and a review of the program. The pilots were briefed on the flight plan and given the nominal flight path parameters (see Figure 5.5.1-1). They were encouraged to take notes on their briefing sheet and to use them during flight. Following the briefing, the pilots entered the cab for instruction on the operational characteristics of the simulator and the test flight tasks (see Appendix F for the briefing checklist).

The pilots were informed of the three basic tasks to be carried out during each flight. The first involved flying the simulator from take-off to landing on the specified flight plan. The second was responding to ATC requests for traffic location. Finally, responses to the alerts were to be made by performing the prescribed actions associated with each alert.

Before participating in the data collection flights, each pilot made a series of practice flights. The purpose of these flights was twofold - to acquaint the pilots with the flight characteristics and dynamics of the simulation airplane model and the flight plan; and to become proficient at performing the correct alert responses. The first practice flight was 31 minutes in which the complete flight pattern was flown. There were no alerts to distract the pilots during this flight. The instructions on how to respond to ATC

Table 5.5.1-1. Pilot Treatment Assignments

	Subject No.		Time-critical test												System validation						
		Location	Primary						Secondary						Pilot				Flight engineer		
		Format	Alpha		Graphic		Both		Alpha		Graphic		Both								
		Voice	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Adv		Conv		Adv	Conv	
		Flight No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Guidance information	1		1	7	11	6	13	12	2	8	9	4	3	5	5	2	6	1	3	4	System A
	2		7	4	12	1	3	10	11	5	6	9	2	8	4	2	3	1	6	5	
	3		10	12	2	9	5	6	7	4	1	8	11	3	6	1	5	2	4	3	
	4		8	1	5	4	7	9	12	6	2	3	10	11	3	2	4	1	5	6	System B
	5		3	11	9	8	12	5	1	2	7	10	6	4	5	1	6	2	3	4	
	6		12	5	10	7	1	3	8	11	4	6	9	2	4	1	3	2	6	5	
Status information	7		5	2	4	3	11	8	9	10	12	7	1	6	3	2	4	1	5	6	System A
	8		2	6	7	5	4	1	10	3	8	11	12	9	5	1	6	2	3	4	
	9		9	8	3	10	2	11	6	1	5	12	4	7	4	1	3	2	6	5	
	10		12	5	10	7	1	3	8	11	4	6	9	2	5	2	6	1	3	4	System B
	11		2	6	7	5	4	1	10	3	8	11	12	9	3	1	4	2	5	6	
	12		5	2	4	3	11	8	9	10	12	7	1	6	6	1	5	2	4	3	

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AIRCRAFT ALERTING SYSTEMS STANDARDIZATION STUDY. VOLUME I. CAND--ETC(U)
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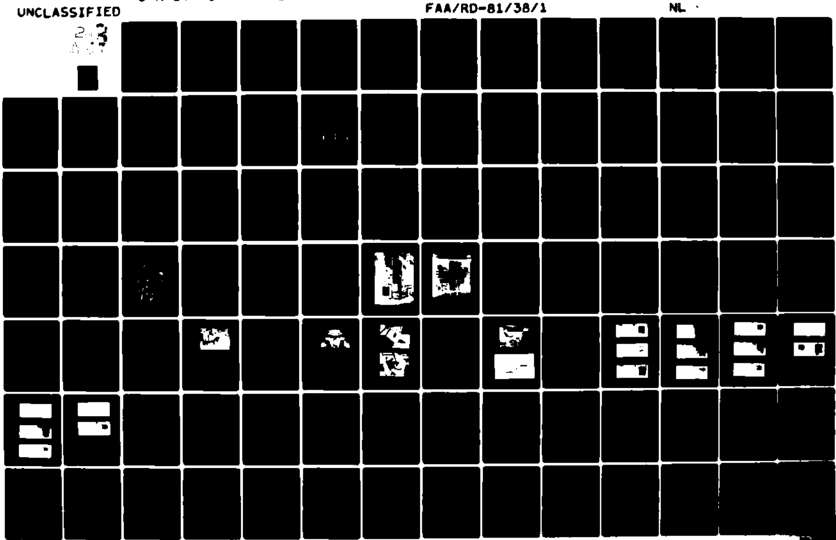
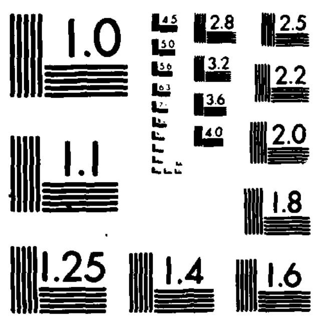




MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Table 5.5.1-2. Daily Test Schedule

	Odd-numbered pilots	Even-numbered pilots
Monday		
000–1:00	Cab warmup and preflight	
0:30–2:30	Pilot training	
2:30–3:45	Flights 1 and 2	
3:45–4:30	Lunch	
4:30–5:45	Flights 3 and 4	
5:45–6:00	Break	
6:00–8:00	Flights 5 through 7	
Tuesday		
000–1:00	Cab warmup and preflight	
1:00–2:30	Flights 8 and 9	
2:30–2:45	Break	
2:45–4:00	Flights 10 and 11	
4:00–4:45	Lunch	
4:45–6:00	Flight 12 and system training	
6:00–6:15	Break	
6:15–7:45	Flights 13 and 14	
Wednesday		
000–1:00		Cab warmup and preflight
0:30–2:30		Pilot training
2:30–3:45		Flights 13 and 14
3:45–4:30		Lunch
4:30–5:30	Flight engineer training	Flight engineer training
5:30–6:45	Flights 15 and 16	Flights 17 and 18
6:45–7:00	Break	Break
7:00–8:15	Flights 17 and 18	Flights 15 and 16
8:15–9:30	Debrief	
Thursday		
000–1:00		Cab warmup and preflight
1:00–2:30		Flights 1 and 2
2:30–2:45		Break
2:45–4:00		Flights 3 and 4
4:00–4:45		Lunch
4:45–5:15		Flights 5 and 6
5:15–5:30		Break
5:30–7:30		Flights 7 through 9
Friday		
000–1:00		Cab warmup and preflight
1:00–2:30		Flights 10 and 11
2:30–2:45		Break
2:45–3:15		Flight 12
3:15–4;30		Debrief

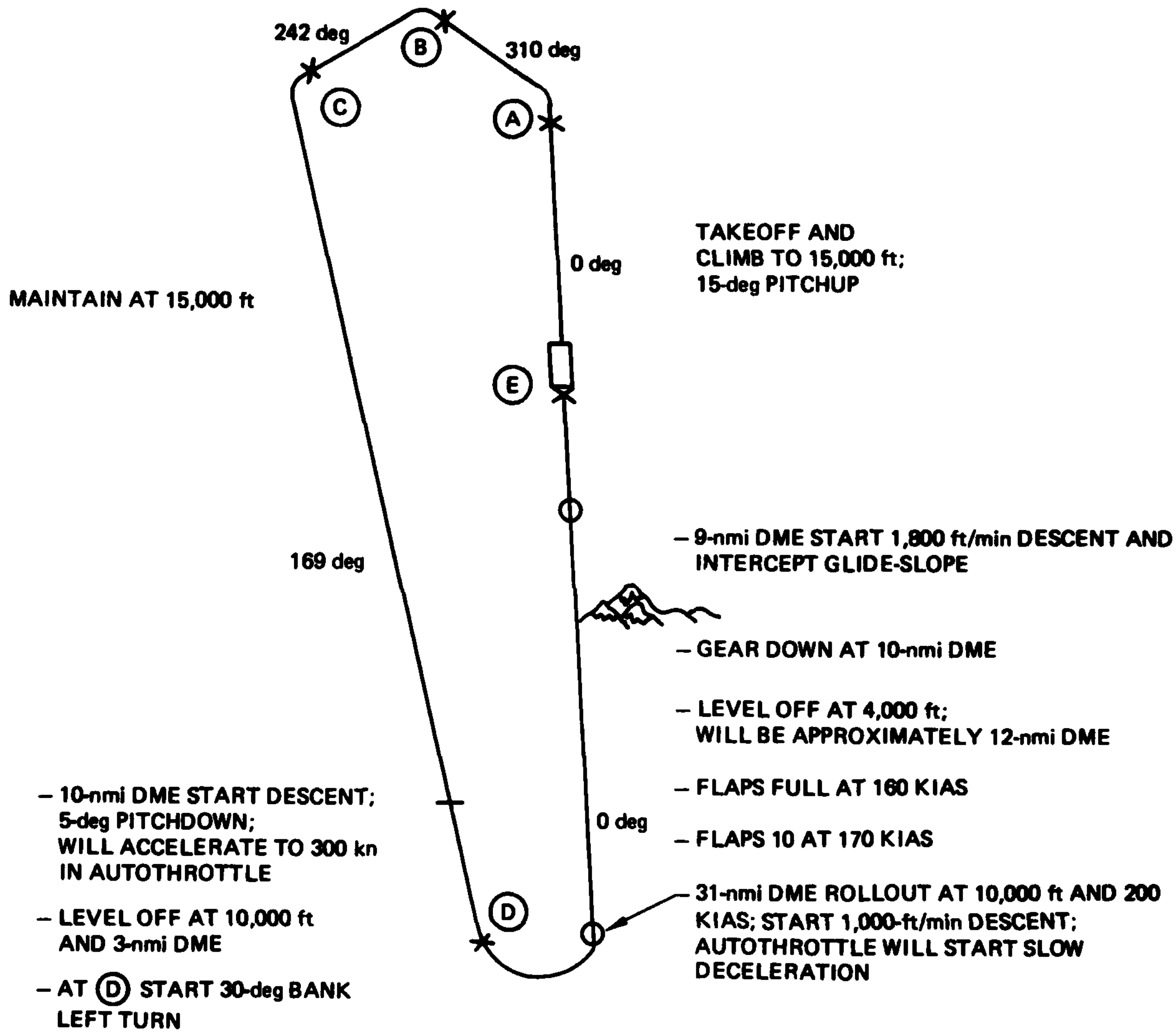


Figure 5.5.1-1. Phase 3 Nominal Flightpath

requests were explained during the practice flight, and any questions the pilot had were answered. Since the pilots had the most problem with EADI symbology (especially the glideslope box), the second practice flight included just the approach from 10 miles out. After these two familiarization flights, the alerts were demonstrated "on the ground" so that the pilot could concentrate on the responses. Then the alerts were repeated and the pilots were asked to respond to them by performing the corrective action. The pilots then flew a full flight with all the system components working. The time for training was two and one half hours.

The test day consisted of eight flights with approximately 4 hours of flying. Brief rest periods were taken throughout the day in an effort to reduce fatigue.

Upon completing the data collection flights the pilots participated in a debriefing session. First, a debriefing questionnaire was completed (see Appendix G). Their impressions of the advanced concepts and the application of the concepts were solicited. The formal debriefings included an informal discussion between the pilots and experimenter and relevant pilot comments were recorded for further evaluation.

The validation tests of the flight engineer alerting system concept were conducted on Wednesday afternoon when both pilots were present. The pilots were given a training session at the flight engineer station to familiarize them with the expected response actions to the alerts and the procedures to be followed during the test flights. After the training session the pilots alternated positions for the afternoon flights.

5.5.2 TIME-CRITICAL WARNING TESTS

The variables investigated in the time-critical tests are described in Section 5.2.2. As in the validation tests, all variables not tested were held constant or controlled to prevent biasing or confounding the results. The values for the variables are presented in the previous section.

As in the validation test, each test flight was 31 minutes in length and contained nine alerts. Four of the alerts were defined as time-critical warnings, four were warnings which were not "time-critical", and one alert was a multiple problem in which at least one alert from each urgency level appeared at the same time. The time-spacing and selection of alerts were performed in the the same manner as for the validation tests. Eleven alert scenarios were developed to reduce the possibility of incuring order effects. The presentation schedule for the treatment conditions is presented in Table 5.5.1-1.

Other than those noted above, there were no other procedural differences between the time-critical tests and the system validation tests.

5.6 PERFORMANCE MEASURES

The performance measures used in the tests fell into two categories - those associated with the flight task and those associated with the alert response tasks. The parameters that reflect how well the pilot was performing the flight task were crosstrack deviation from the flight path, altitude deviations, wheel and column reversals, landing performance, and speed and accuracy of detection of the outside visual targets. The parameters were especially important for the time period immediately around the alerts because they provide a measure of the efficiency and effectiveness of the pilot in performing the flight task. A second set of dependent variables, used to quantify the responses to the alerting system, included the time and accuracy of alert detection, the time and accuracy of the response to the alert, the system component used, and the sequence in which the pilot performed the alert cancellation.

Finally, subjective data expressing the pilot's opinions about the various alerting system characteristics were gathered for all test configurations. The pilots were asked to comment on and rate the effectiveness of the candidate systems, clarity of the messages, format and system components.

5.7 DATA REDUCTION AND ANALYSES

The data obtained in the Phase 3 testing falls into two general categories - objective (or performance) data and subjective (questionnaire/debriefing) data. A time-based tabulation of all events that occurred in the cab, switch and light states, displayed messages and fault situation initiation, was generated from the data. From this tabulation, sums, means and standard deviations were calculated for all performance variables. The performance was analyzed with respect to all the alerts and was also partitioned into the various alert categories. Analyses of variance were performed on the reduced data to determine if the various treatment conditions had a differential affect upon performance.

The statistical model for the system validation test was a straight comparison between the conventional alerting system and the advanced alerting concepts. This resulted in a two factor analysis of variance with a single testable effect - the alerting system.

The time-critical tests on the other hand, had a much more complex model since they were of a mixed design. All pilots had the treatment conditions associated with three of the variables, but the fourth variable (message format) divided the pilots into two groups. The model and source table for these analyses are presented in Table 5.7-1.

Since validation testing requires that system developers be very sure before they reject any candidate system concept, and since the time critical tests were exploratory in nature, an error probability of .10 was selected as a test for significance for the statistical tests performed on both experiments.

5.7.1 SYSTEM VALIDATION TESTS—EXPERIMENTAL HYPOTHESIS

The following were the hypotheses upon which the validation tests were based. Each of the hypotheses can be equally stated for all levels of alerting urgency, i.e., warning, caution and advisory.

Table 5.7-1. Sample of Analysis of Various Model and Summary Table for a Factorial Experiment With Repeated Measures on Some of the Factors

Note: The example is a two-factor experiment with repeated measures on one factor.

Model		
$X_{ijk} = \mu + \sigma_i + \gamma_{k(i)} + \beta_j + \sigma\beta_{ij} + \beta\gamma_{jk(i)} + \epsilon_{k(ij)}$		
Summary Table		
Source	Expected mean square	F ratio
A	$\sigma_e^2 + ba\,\sigma_s^2 + nb\,\sigma_A^2$	MS_A/MS_{sub}
Subject within A	$\sigma_e^2 + ba\,\sigma_s^2$	
B	$\sigma_e^2 + a\,\sigma_{Bs}^2 + na\,\sigma_B^2$	MS_B/MS_{Bs}
A x B	$\sigma_e^2 + a\,\sigma_{Bs}^2 + n\,\sigma_{AB}^2$	MS_{AB}/MS_{Bs}
B x subjects within A	$\sigma_e^2 + a\,\sigma_{Bs}^2$	

1. There is no difference in the pilots detection time between the conventional and advanced alerting systems A or B.

2. Pilot response time is not affected by the alerting system used.

3. There is no difference in the number of missed alerts between the conventional alerting system and concepts A or B.

4. The type of alerting system used has no effect on the pilot's flight performance.

5. Flight performance is not affected by the urgency of the alert.

6. There is no difference in the flight engineer's response time between the conventional and advanced alerting systems.

7. There is no difference in the number of missed alerts by the flight engineer using conventional and advanced alerting systems.

8. The pilots have no preference for either the conventional or advanced visual displays.

9. The pilots have no preference between the conventional discrete sounds and the advanced master aural alerts.

10. The pilots have no preference between verbal and non-verbal alerts.

5.7.2 TIME-CRITICAL WARNING TESTS--EXPERIMENTAL HYPOTHESES

The following are the hypotheses upon which the time-critical warning tests were based:

1. There is no difference in detection times between time-critical and other warnings.

2. There is no difference in response times between time-critical and other warnings.

3. The error distribution of the time-critical warnings does not change for different presentation formats, message content, voice formats, or display locations.

4. Detection or response times for time-critical warnings are the same when the location of the visual information is at a 30° visual angle or at a 15° visual angle.

5. There is no difference in the detection or response times for the time-critical warnings among the three presentation formats - alphanumeric, graphic or both.

6. There is no difference in the detection or response times for time-critical warnings between status and guidance messages.

7. The presence or absence of a voice alert has no effect on the detection or response times for time-critical warnings.

8. Flight performance is not affected by alert type, time-critical warnings or non-time-critical warnings.

9. Flight performance is not affected by the location of the time-critical display.

10. Flight performance is not affected by the presentation formats of the time-critical warnings.

11. Flight performance is not affected by the message formats of the time-critical warnings.

12. Flight performance is not affected by the presence or absence of a time-critical voice alert.

13. The pilots had no preference for the time-critical warning display location, presentation format, message format or voice.

5.8 TEST RESULTS

Although some of the results reported in the following sections as being statistically significant may appear to be of insufficient magnitude to be of practical importance, this may be a false assessment of the results, however, due to the nature of the tests. It must be kept in mind that the pilots knew that alerts were going to occur during the flight, which would result in a response that was faster than would normally occur. Since the speed of a response is bounded on the low side by physical parameters, (i.e., recognition and reaction time) smaller differences between treatments are to be expected when working with shorter response times. It is also expected that any differences discovered in this type of test would be magnified under actual flight conditions.

5.8.1 SYSTEM VALIDATION RESULTS

5.8.1.1 DETECTION TIMES

Alert detection time was defined as the time between the onset of the alert and the depression of the left hand thumb switch by the pilot. The analysis of variance summary tables are presented in Table 5.8.1.1-1.

The advanced systems consistently produced shorter mean detection times than the conventional system. These differences in times with the system A were significant for both Warnings ($F = 5.25$ df 1,9) and advisories ($F = 3.4$ df 1,9). Although the time differences were small (1.88 seconds versus 1.48 seconds and 2.15 seconds versus 1.81 seconds respectively) the pilots consistency led to the significance of the data. The pilots who were tested using system B, however, were more variable in their detection with a standard deviation of 1.57 seconds as compared to 0.26 second for system A. The result suggests that the use of the voice selection option added variability to the data which in turn made it more difficult to identify true differences. System B pilots also took longer on the average to detect the alerts both for the advanced and conventional systems (2.02 seconds and 2.53 seconds versus 1.54 and 1.86 seconds). The result of the greater variability in responses was that even though the differences between advanced and conventional system

response times for warning and advisories was larger with System B than with System A the differences were not significant. Illustrations of the detection times for Systems A and B are presented in Figures 5.8.1.1-1 and 5.8.1.1-2.

The pilots varied widely on their use of voice in System B. Both extremes were observed. One pilot never used the voice and one pilot initiated it for all the warnings and cautions. For those pilots who used the voice, warnings were always requested equal to or more often than caution (25 to 17).

5.8.1.2 VALIDATION RESPONSE TIMES

Pilot response time was defined as the time from the alert onset to the completion of the response perscribed for that alert. The analysis of variance summary table for the system validation response times is presented in Table 5.8.1.2-1.

As with detection times, the advanced alerting systems consistently produced shorter response times than did the conventional system. Both advanced systems produced significantly shorter (F = 3.7 & 3.5 df 1,14 and 1,9) mean response times to cautions (5.0 and 5.4 seconds) than did the conventional (6.6 and 7.0 seconds).

There was no difference in the response times to warnings or advisories between the advanced and conventional systems. The response times for System A and B are graphically compared with the conventional system in Figures 5.8.1.2-1 and 5.8.1.2-2, respectively.

Response times were also obtained as a validation of the use of an advanced display for the Flight Engineer. The mean response time to warnings was significantly shorter (F = 5.19 df 1,9) for the advanced display (5.52 seconds) than for the conventional alerting scheme (8.36 seconds). Although not statistically significant, the cautions were responded to faster with the advanced display (7.8 seconds versus 9.1 seconds). The relationship is illustrated in Figure 5.8.1.2-3.

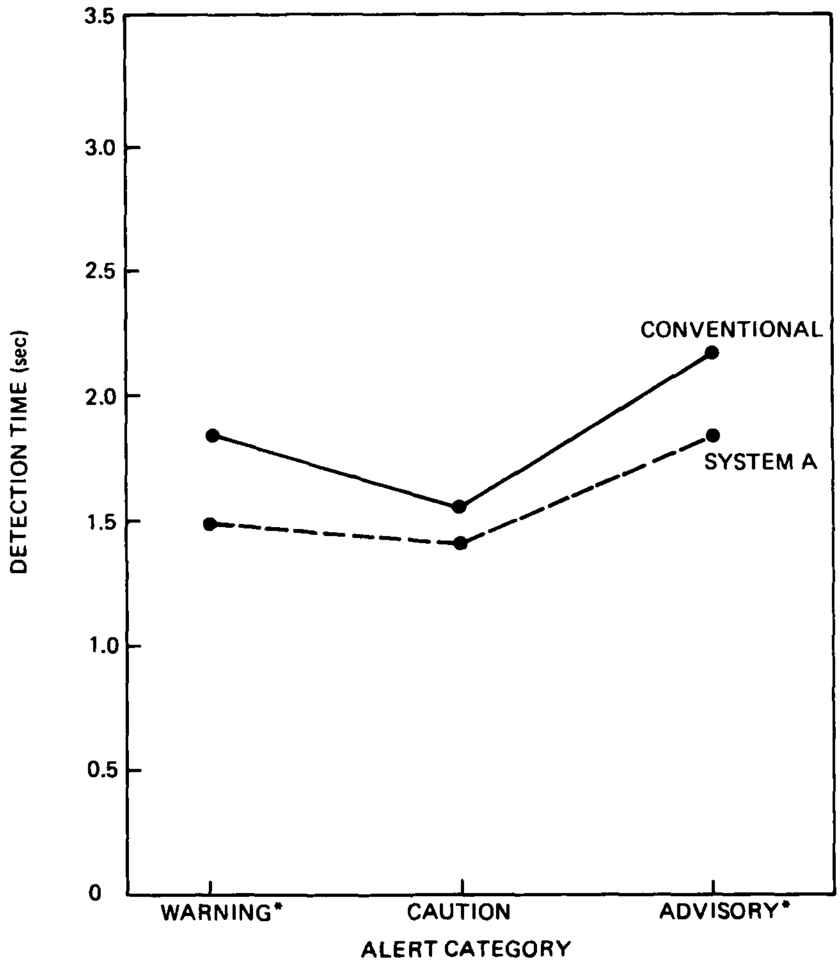
Table 5.8.1.1-1. System Validaton Detection Time Summary (Composite of the ANOVA's)

Source	Sum of squares	Degrees of freedom	Mean square	F	Probability F exceeded
System A					
Warning	0.794	1	0.794	5.25	0.04 *
Error	1.359	9	0.151		
Caution	0.124	1	0.124	2.01	0.189
Error	0.545	9	0.061		
Advisory	0.560	1	0.560	3.40	0.10*
Error	1.482	9	0.165		
System B					
Warning	1.244	1	1.244	1.08	0.339
Error	6.917	6	1.152		
Caution	0.110	1	0.110	0.05	0.817
Error	11.315	6	1.885		
Advisory	2.081	1	2.081	0.39	0.552
Error	31.506	6	5.251		

Table 5.8.1.2-1. System Validation Response Time Summary (Composite of the ANOVA's)

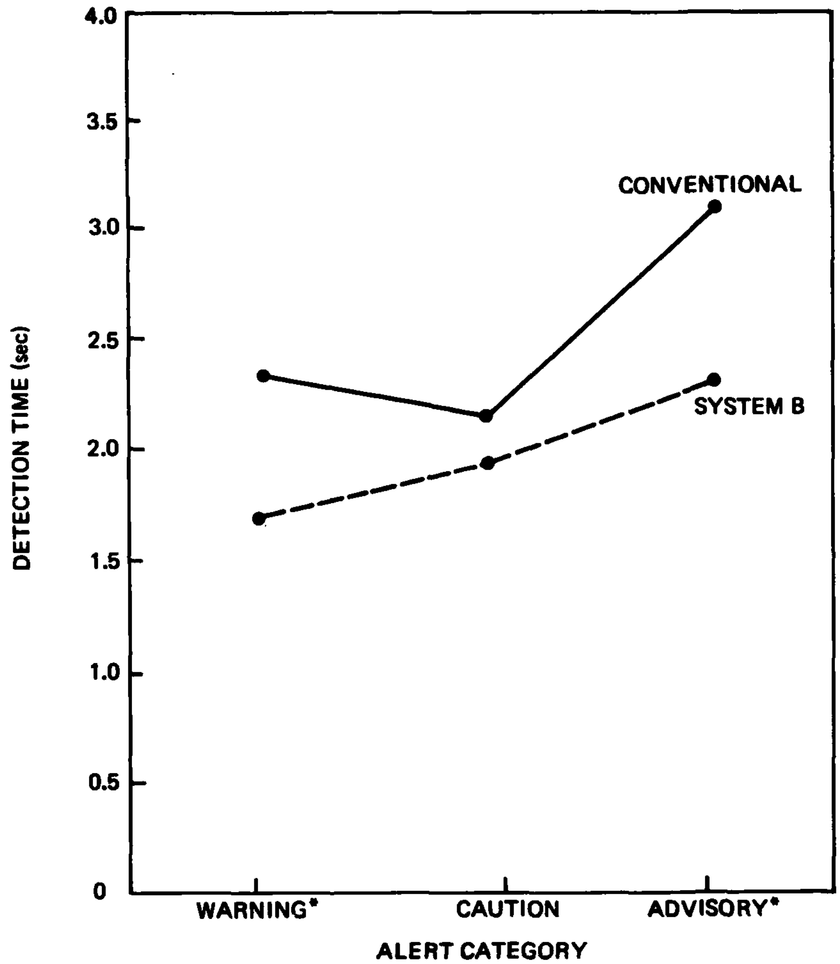
Source	Sum of squares	Degrees of freedom	Mean square	F	Probability F exceeded
System A					
Warning	2.787	1	2.787	1.54	0.23
Error	25.351	14	1.811		
Caution	19.214	1	19.214	3.66	0.07 *
Error	73.413	14	5.243		
Advisory	0.037	1	[illegible]	0.01	0.92
Error	49.877	14	3.562		
System B					
Warning	0.820	1	0.820	1.22	0.29
Error	6.059	9	0.673		
Caution	12.319	1	12.319	3.52	0.09*
Error	31.497	9	3.50		
Advisory	0.024	1	0.024	0.008	0.93
Error	25.892	9	2.876		

*Significant at the .10 level or better.



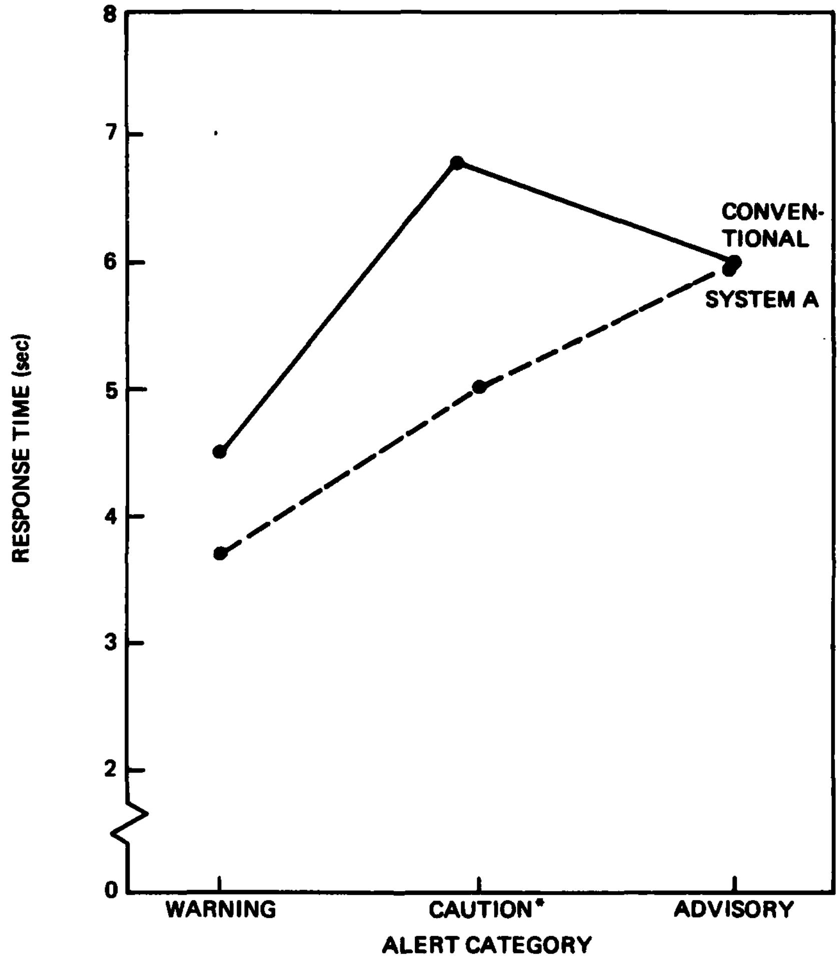
*Significant at 0.10 level.

Figure 5.8.1.1-1. Candidate System A—Detection Time



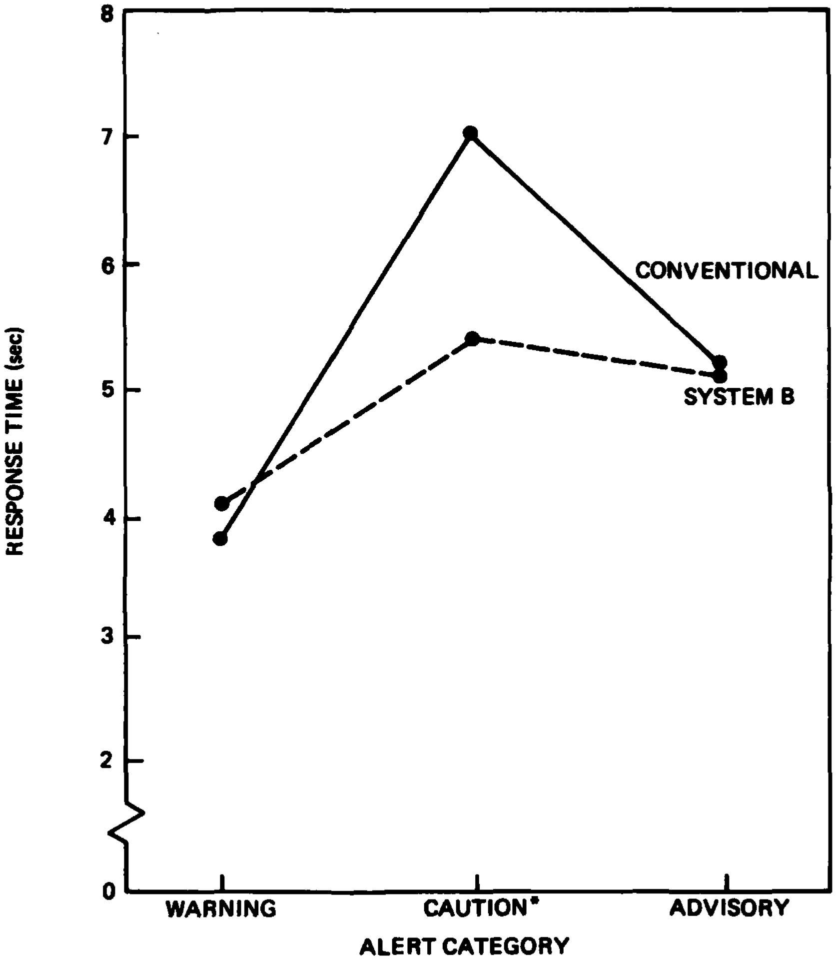
*Significant at 0.10 level.

Figure 5.8.1.1-2. Candidate System B—Detection Time



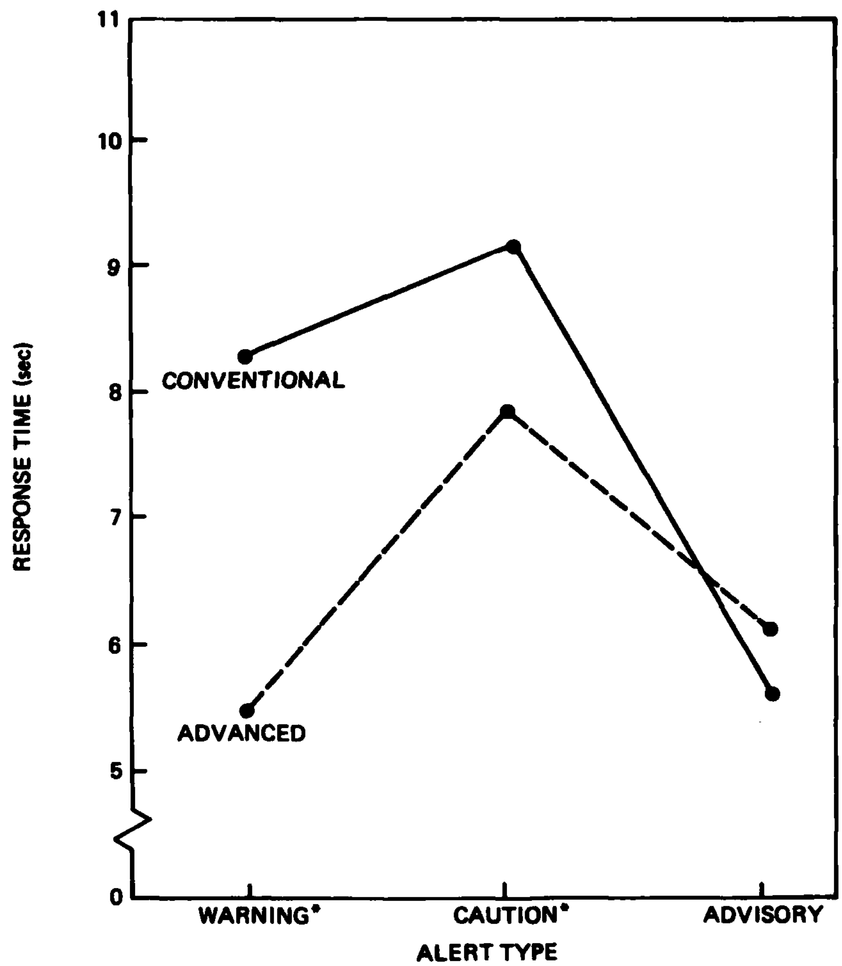
*Significant at 0.10 level.

Figure 5.8.1.2-1. Candidate System A—Response Time



*Significant at 0.10 level.

Figure 5.8.1.2-2. Candidate System B—Response Time



*Significant at 0.10 level.

Figure 5.8.1.2-3. Flight Engineer System Validation—Response Time

5.8.1.3 MISSED ALERTS

Each alert remained active for 30 seconds. If, after that time, the pilot had not made the specified response the alert was considered missed. Out of 216 alerts presented with the conventional system 7 were missed or 3 percent. Of those 7 missed alerts 3 were warnings and 3 cautions. The warning alerts missed all were aural-presentation-only type alerts (e.g., overspeed or cabin altitude).

The advanced systems had only two missed alerts between them (one advisory with System A and one caution with System B) or less than one percent.

The flight engineers exhibited a larger missed alert rate. Using their conventional system they missed 30 alerts out of 90 possible or thirty-three percent. The breakdown of the missed alerts was 10 warnings, 11 cautions and 9 advisories. Using the advanced flight engineer's system however, reduced the number of missed alerts to 7 or about 8 percent. The were also evenly distibruted, with 2 warnings, 3 cautions, and 2 advisories. These data are presented graphically in Figure 5.8.1.3-1.

5.8.1.4 PILOT PREFERENCES

The debriefing questionnaire is presented in Appendix G. All of the pilots preferred the advanced systems over the conventional. None of the pilots felt that the conventional system was more attention-getting or provided easier problem identification. Ninty-three percent of the pilots found the advanced visual system easier to use and eighty-five percent responded in the same manner for the master aural sounds. Seventy percent of the pilots indicated a preference for a voice system to augment the visual alerts while eight percent preferred the master aural alert only. Eight percent of the pilots also felt that the master aural sound was a more effective attention-getter than the combination of a sound and a voice. None of the pilots felt that the intensity level of the alerts, both master sound and voice, (8dB above ambient) was not loud enough. Seventy-seven percent indicated that 8dB was the appropriate level, however, twenty-three percent said it was too loud.

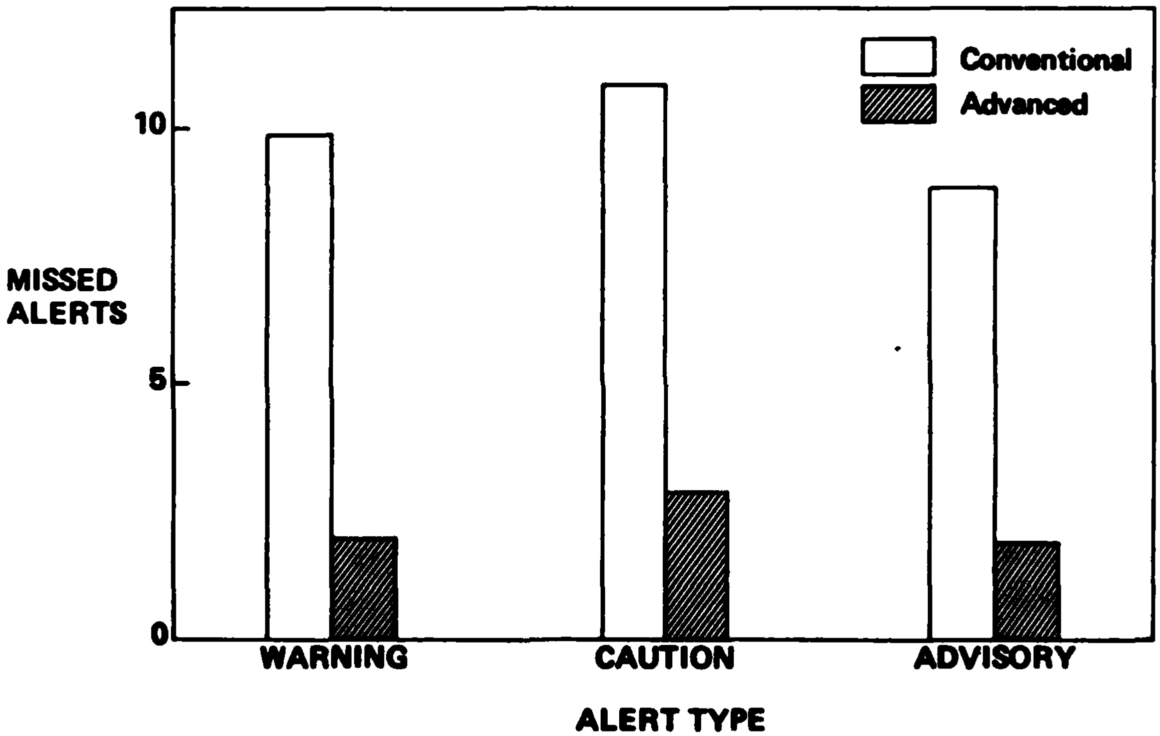


Figure 5.8.1.3-1. Flight Engineer System Validation—Missed Alerts

The pilots were then asked to rate system features on the following 5 point scale:

1 = Unacceptable - major changes necessary
2 = Poor - major changes recommended
3 = Fair - minor changes recommended
4 = Good - minor changes beneficial
5 = Excellent - no changes recommended

All of the characteristics of the visual information display had an average rating of 4.0 or better. These characteristics included, location, character size, alert color, brightness, character separation, message content and the new message indicator. The auditory display also received high ratings. The number of master aural alerts received an average rating of 4.4 with both the warning and advisory sounds receiving ratings above 4.0 (4.2 & 4.1 respectively). The caution sound had a mean rating of 3.1 with the majority of the pilots' comments centered around the urgency of the sound and its perceived resemblance of the warning sound. The voice alerts had a mean rating of 4.5 or better on ease of use, lack of confusion with other communication, message content and voice type (female). The following characteristics of voice received a mean rating of 4.0 to 4.5; intelligibility, loudness and repetition rate.

Finally, the pilots were asked to list the 5 things that they most liked about the advanced alerting systems and the 5 things they liked least. Eighty-five percent of the pilots listed the central location for all alerts as a highly preferred feature. Other features that were listed as "most liked" items were: unique tone for warning, caution and advisory (70%); voice on cautions (54%); volume of the auditory components (31%); separate colors for each alert category (23%); features receiving less than twenty percent of the pilots responding are not included here.

Only one feature of the advanced systems was liked least by more than twenty percent of the pilots, and that was the seeming urgency of the caution sound (39%).

5.8.2 TIME-CRITICAL TEST RESULTS

5.8.2.1 DETECTION TIMES

The analysis of variance summary table for the time-critical alert detection time is presented in Table 5.8.2.1-1. None of the main effect variables (location, presentation format, voice, or message information) had a measurable effect on the mean detection time. However, there was a significant interaction (F = 2.87 df 2,16) between the presentation format and the message content. This interaction indicates that the mean detection times are significantly shorter for the guidance information if graphics are used (1.64 seconds and 1.08 seconds) than for the status messages (1.96 seconds and 1.98 seconds). This effect is illustrated in Figure 5.8.2.1-1.

There was no measurable difference between the detection of time-critical and non-time-critical warnings. In Figure 5.8.2.1-1 the comparison is shown between the non-time-critical warnings (▲) which were alphanumeric status messages and the corresponding time-critical warning (1.57 seconds versus 1.52 seconds). Finally, the presentation media for the time-critical warnings had no effect on the detection of the non-time-critical warnings.

5.8.2.2 RESPONSE TIMES

The analysis of variance summary table for the response times to time-critical warnings is presented in Table 5.8.2.2-1. The main effect attributed to message information type was significant (F = 3.59 df 1,10) with the mean response time for guidance messages (2.58 seconds) being shorter than for status messages (2.95 seconds). No other main treatment conditions had by themselves a measurable effect on response time. There were interactive effects, however, which did provide measurable differences. The interaction between presentation format (alphanumeric, graphic and both) and the type of information presented (status or guidance) was very high (F = 4.49 df 2,20). This interaction is presented in Figure 5.8.2.2-1. It can be seen that the guidance messages presented graphically are responded to faster (2.51 seconds) than any presentation of status information. Graphic presentation of status information resulted in the longest mean response time (3.04 seconds).

Table 5.8.2.1-1. Summary Table for Time-Critical Detection Time

Source	Sum of squares	Degrees of freedom	Mean square	F	Probability F exceeded
Mean	296.43463	1	296.43463	50.26492	0.000
Message content	5.12679	1	5.12679	0.869	0.37
Error	47.17956	8	5.89745		
Display location	0.28045	1	0.28045	0.363	0.56
Display location x message content	0.29145	1	0.29145	0.377	0.55
Error	6.17637	8	0.77205		
Presentation format	2.52754	2	1.26377	2.203	0.14
Presentation format x message content	3.28749	2	1.64374	2.865	0.08*
Error	9.17772	16	0.57361		
Display location x presentation format	2.12321	2	1.06160	0.804	0.46
Display location x presentation format x message content	2.11918	2	1.05959	0.803	0.46
Error	21.10847	16	1.31928		
Voice	0.50955	1	0.50955	1.028	0.34
Voice x message content	0.16812	1	0.16812	0.339	0.57
Error	3.96502	8	0.49563		
Display location x voice	1.06507	1	1.06507	1.542	0.24
Display location x voice x message content	0.06923	1	0.06923	0.100	0.76
Error	5.52552	8	0.69069		
Presentation format x voice	0.54523	2	0.27261	0.446	0.64
Presentation format x voice x message content	0.83738	2	0.41869	0.685	0.51
Error	9.77446	16	0.61090		
Display location x presentation format x voice	0.30163	2	0.15081	0.601	0.56
Display location x presentation format x voice x message content	0.33872	2	0.16936	0.675	0.52
Error	4.01502	16	0.25094		

*Significant at the .10 level or better.

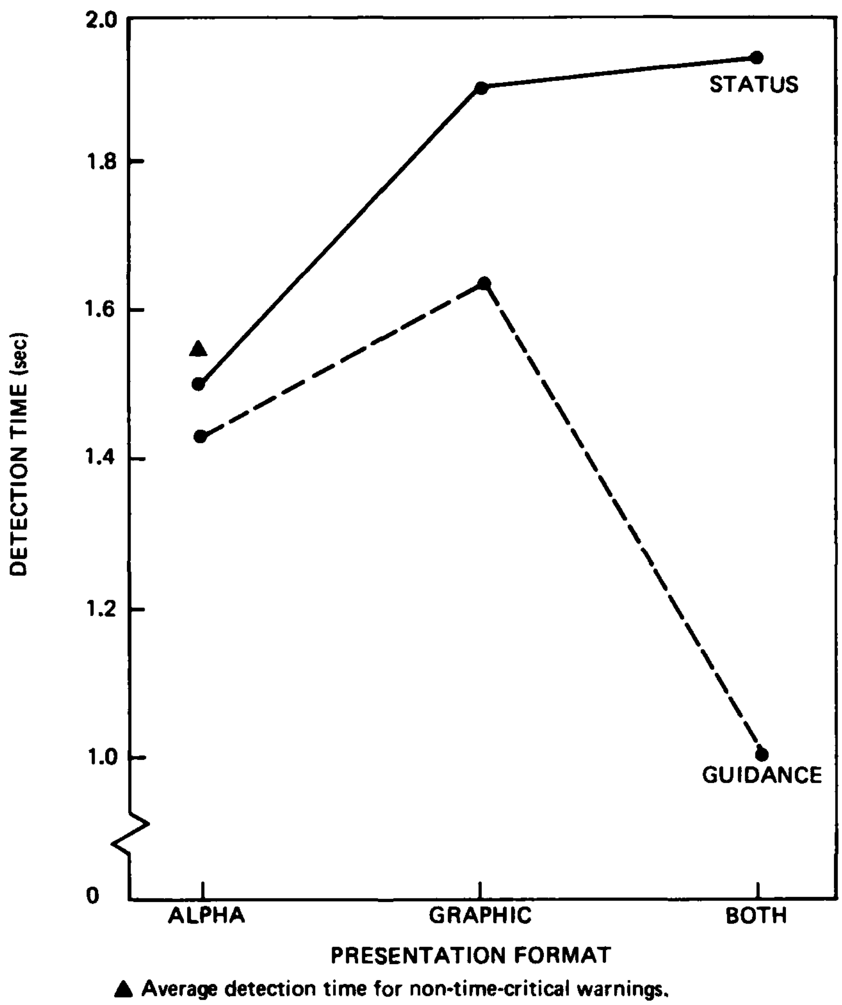
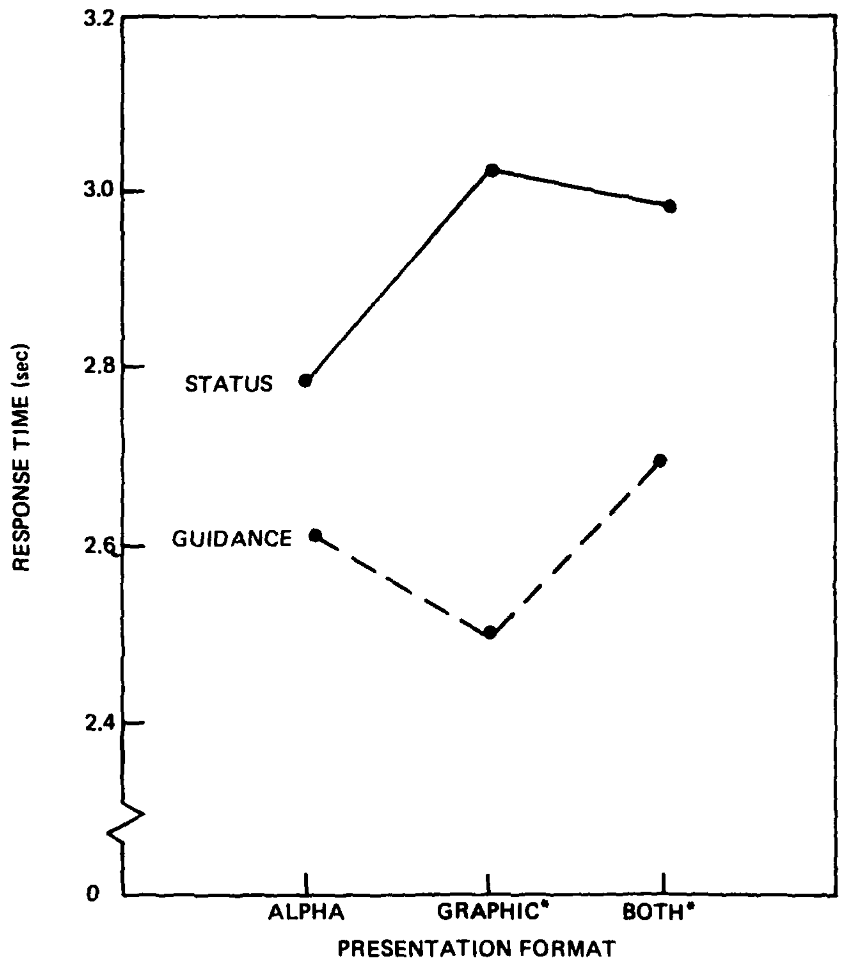


Figure 5.8.2.1-1. Detection Time Interaction Between Presentation Format and Message Content

Table 5.8.2.2-1. Summary Table for Time-Critical Response Time

Source	Sum of squares	Degrees of freedom	Mean square	F	Probability F exceeded
Mean	1101.20557	1	1101.20557	606.99744	0.000
Message content	1.30474	1	1.30474	3.596	0.09*
Error	3.62837	10	0.36284		
Display location	0.00388	1	0.00388	0.005	0.94
Display location x message content	0.44745	1	0.44745	0.633	0.44
Error	7.06132	10	0.70613		
Presentation format	0.26088	2	0.13044	0.448	0.64
Presentation format x message content	2.61547	2	1.30773	4.497	0.02*
Error	5.81526	20	0.29076		
Display location	0.31824	2	0.15912	0.735	0.49
Display location x presentation format x message content	1.20346	2	0.60173	2.731	0.07*
Error	4.32581	20	0.21629		
Voice	0.12244	1	0.12244	0.412	0.53
Voice x message content	0.00375	1	0.00375	0.012	0.91
Error	2.96806	10	0.29681		
Display location x voice	0.00839	1	0.00839	0.023	0.88
Display location x voice x message content	0.86289	1	0.86289	2.429	0.18
Error	3.55166	10	0.35517		
Presentation format x voice	0.04943	2	0.02472	0.110	0.89
Presentation format x voice x message content	0.19669	2	0.09835	0.439	0.65
Error	4.47214	20	0.22361		
Display location x presentation format x voice	1.03525	2	0.51763	2.238	0.13
Display location x presentation format x voice x message content	1.05758	2	0.52879	2.868	0.08*
Error	3.64682	20	0.18234		

*Significant at the .10 level or better.



*Significant at 0.10 level.

Figure 5.8.2.2-1. Response Time Interaction Between Presentation Format and Message Content

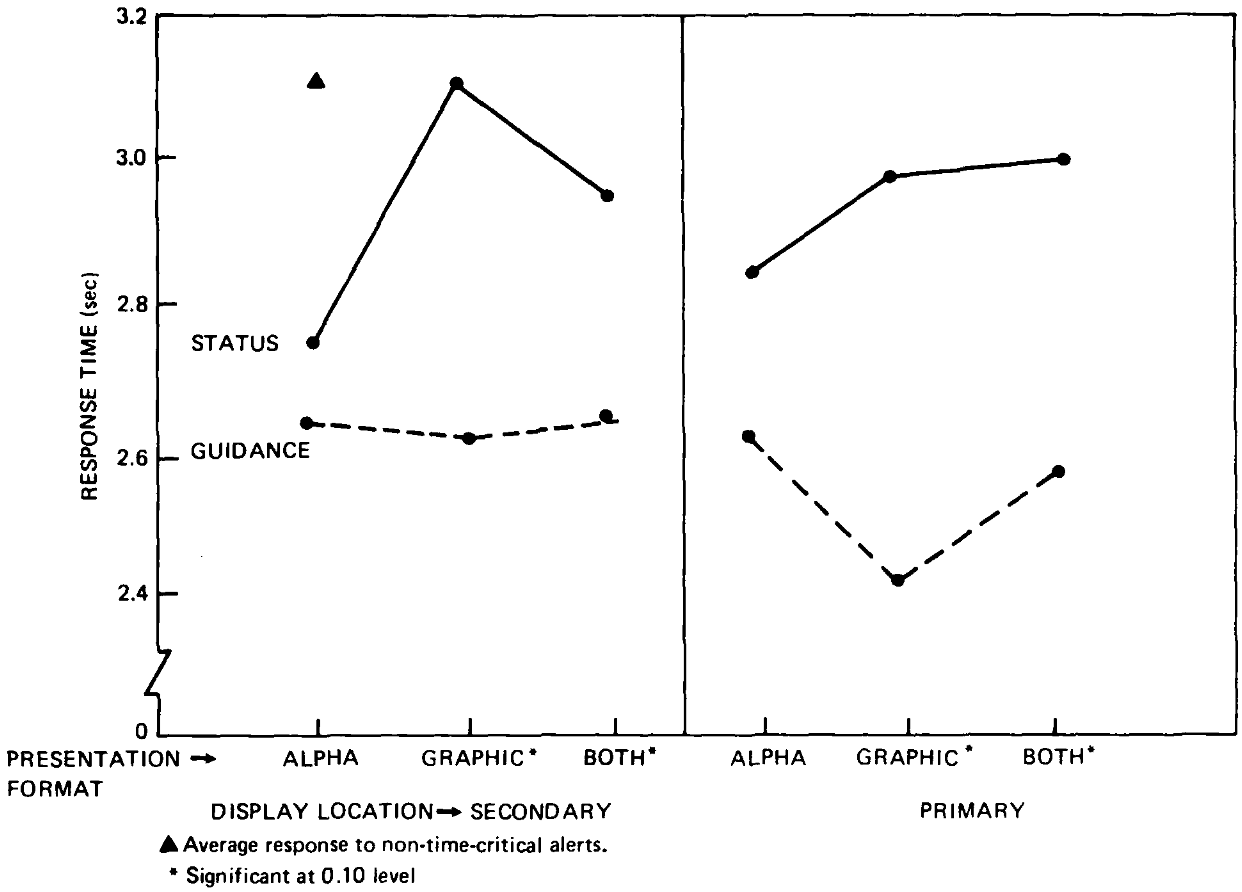


Figure 5.8.2.2-2. Mean Response Time as a Function of the Interaction Between Display Location, Presentation Format, and Message Content

The addition of the display location to presentation format and message information also resulted in a significant interaction (F = 2.73 df 2,20). Figure 5.8.2.2-2 illustrates this interaction. It also illustrates the significant difference between the mean response times for non-time-critical alerts (3.15 seconds) ana the corresponding time-critical alert (2.71 seconds). When guidance information was presented graphically (or graphically with alphanumerics) in the pilot's primary field of view, the resulting mean response times (2.41 seconds and 2.61 seconds) were significantly shorter than using status information (2.95 seconds). Presenting status information graphically in the pilot's secondary field of view resulted in the longest mean response time (3.09 seconds).

Finally, the partitioning of voice out of this interaction also produced significant effects ($F = 2.87$ df 2,20). This four-way interaction is illustrated in Figure 5.8.2.2-3. With these data the treatment condition which produced the shortest response time can be identified. When the pilots were presented guidance information graphically in their primary field of view accompanied by voice they responded the fastest (2.29 seconds). Graphic presentation of the status information resulted in the slowest mean responses for both voice (3.19 seconds) and no voice (3.22 seconds) conditions. As can be seen in the illustration, except for the status alerts in the secondary field of view with voice, the alphanumeric format and the combined alpha-graphic format resulted in essentially the same response times for their particular treatment conditions.

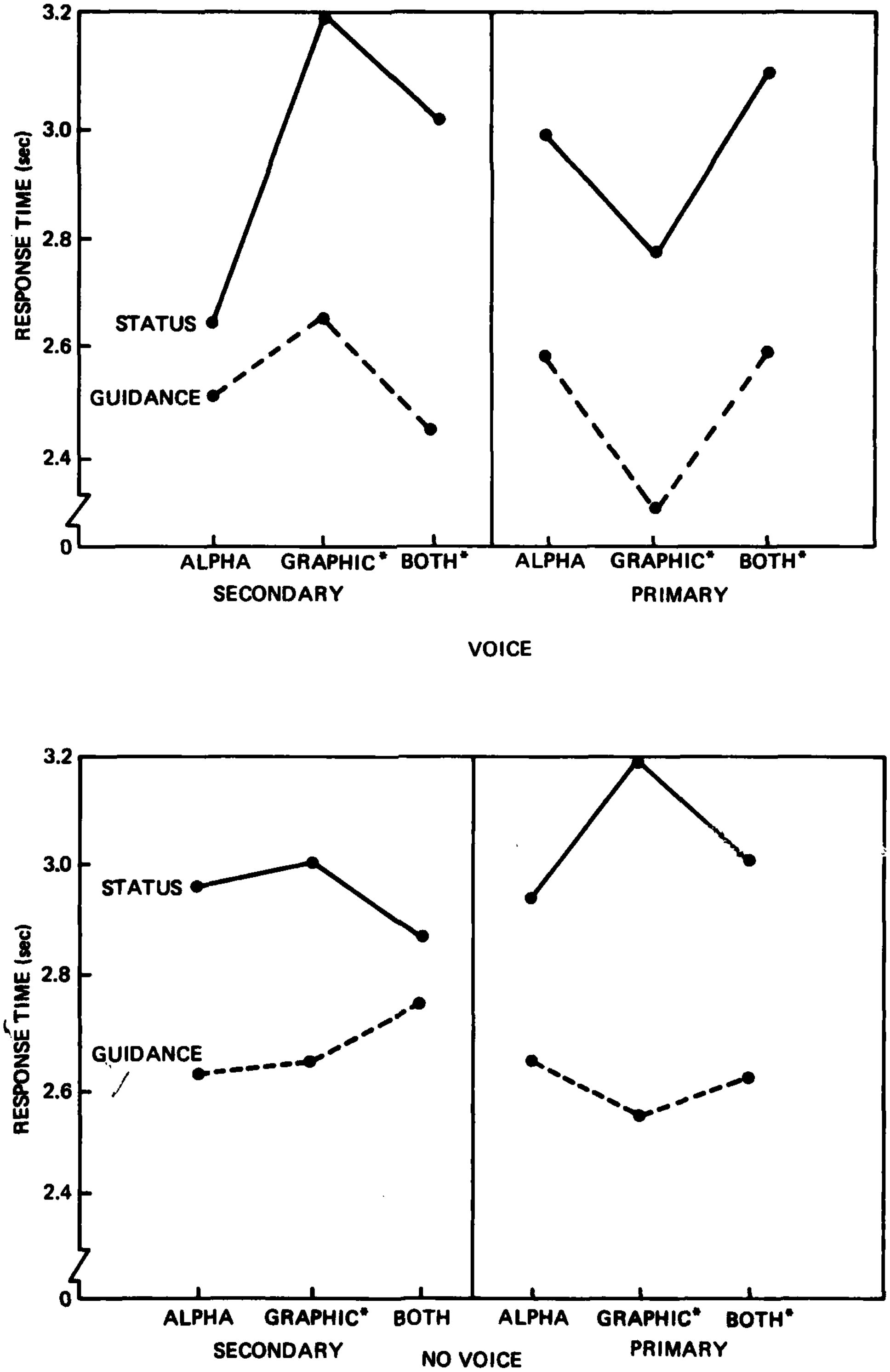
5.8.2.3 MISSED ALERTS

The pilots responded to all of the alerts both time-critical and non-time-critical warnings during the time-critical testing. This result corresponds with the data from the system validation tests in which no warnings were missed with the advanced systems.

5.8.2.4 PILOT PREFERENCES

The debriefing questionnaire is presented in Appendix G. Eighty-three percent of the pilots said that for time-critical warnings they would prefer guidance information to facilitate the correct response. There was no clear preference for the alert location. Eighty-five percent of the pilots said that they could see the time-critical alerts equally as fast in the primary and secondary fields-of-view. Sixty-nine percent had no preference for either location. However, during the debriefing interview 70% of the pilots said that if the alert message was providing guidance information then consideration should be given to presenting it on the primary guidance instrument, the EADI.

Sixty-one percent of the pilots felt that the graphics used for the test were too cluttered. None of the pilots rated the graphics alone as easiest to use, promoting fastest response, promoting the fewest errors or as the preferred



*Significant at 0.10 level

Figure 5.8.2.2-3. Response Time Interaction Between Display Location, Presentation Format, Message Content, and Voice

presentation format. They reported that the graphic presentation for the guidance information did not put enough emphasis on the guidance element and thus were less effective than they could have been. Although they had difficulty with the graphic presentation, 46% of the pilots said that they would like to see a combination of alphanumeric and graphic formats.

6.0 DISCUSSION AND CONCLUSIONS

The discussion of the system simulation tests will focus on the validation of the candidate alerting concepts and the design features which affect the pilot's response to time-critical alerts.

6.1 SYSTEM VALIDATION

In the system validation tests, two candidate advanced alerting system concepts were compared to a conventional alerting system. In all areas of measurement, the advanced systems resulted in pilot performance that was as good or better than the conventional system. This was true even for the response times with System B where the pilots were using the optional voice much more than would be expected after the novelty wore off (50% of the time). Therefore, it can be concluded that the candidate alerting concepts appear to represent viable alerting system designs.

The alerting system has four primary functions, to attract the crews attention, identify the urgency level of the alert, direct crew attention to the source of the problem, and provide feedback on the adequacy of the corrective action. It was expected that the changes in the system components between the advanced and conventional systems should produce detectable changes in the ability of the systems to perform these functions.

If detection time is defined as a measure of the attention-getting function of the system, the results indicate that there was a significant improvement of the advanced over the conventional systems. Warning and advisory alerts had significantly shorter mean detection time with System A than with the conventional system. Larger differences in mean detection time were produced by System B; however, the increase in pilot variability caused these differences to be classified as insignificant. The data suggest that the higher variability was the result of using the voice selection. Therefore, the results of the System B validation tend to support those from System A. When considering the attention-getting features of the warning level alerts, the advanced and conventional systems differed in both the visual and auditory components. The advanced systems had a single master light and sound for all

warnings, and the conventional had different lights and sounds for each alert. The reduction in the number of sounds should not in theory aid in detection but rather reduce confusion in identification. Therefore, the consolidation of all the discrete warning lights into a single master alert located in the pilot's primary field of view seems to have resulted in an improvement of the detection performance. This hypothesis is supported by the results of the caution alerts. Both the conventional and advanced systems had a single master visual light located in the pilot's primary field of view. The advanced systems also had a master caution sound to attract the pilot's attention. The lack of measurable difference in the mean detection times for caution alerts between the systems indicates that the master visual attention-getter is being used by the pilots. In the absence of a master light in the primary field of view (or the existance of a visual workload reducing the probability of seeing the light) the master aural provides the necessary attention-getting function. This is demonstrated by the mean detection times for advisories. Even the abbreviated sound (single stroke chime) used for the advisories in the advanced system was sufficient to result in significantly shorter mean detection times than were found with the conventional system which had no master attention-getters for advisories.

In a recent study Boucek, et al., (1980) found that pilots use the urgency level provided by the master attention-getters in making their response decisions. As seen in both of the advanced systems, the response to cautions is slower than to the warnings even though they were detected in the same time. This seems to indicate that the pilot was making response decisions based on alert urgency. Using the data from System A, because it is not confounded with the optional use of voice, the same trend can be observed for the advisory alerts. Again, as was found by Boucek, et al., (1980), if the pilot has to begin his response, i.e., looking at the annunciator panel to get the alert information; he will continue the response regardless of the urgency level. This can be seen in the conventional system where there is no master indication for advisory alerts and therefore no preliminary urgency information; in this case the mean response times for the advisories are shorter than for the cautions.

Total perception of the alert urgency also seems to be a factor in a pilot's response. In the advanced systems the warning and caution alerts receive essentially the same treatment by the alerting system (master light, master aural and visual information display) differing only in the coding of these components. On the other hand, the conventional system treats warnings (large red light and loud sound) quite differently from cautions (smaller amber light and subdued readout in secondary field of view). The data reflects these differences. There is a significantly greater disparity in the mean response times between warnings and cautions for the conventional system than for the advanced systems.

If the flight crew includes a flight engineer, the results of the study indicate that his station should contain the visual display information components of the advanced system. Making the alerting system information available to the flight engineer in a central location aids in system management and can be used to provide checklists and procedural information.

Along with the objective data obtained in the tests, pilot preference data concerning candidate concepts were also obtained. Both in the supplemental and system validation tests, user reaction was very favorable. However, one area which the pilots felt that a change was needed was the master caution sound. Boucek, et al, (1980) recommends the system should take advantage of pilot's preconceived notions as to how alerts should sound. For cautions, a constant or steady-state sound of mid-range frequency was recommended. However, it was also recommended that no sound previously used on a flight deck be used for the higher level alerts to avoid confusion. When the possible steady-state sounds were investigated it was discovered that they had been used or closely resembled a currently used sound. Therefore, a pulsing sound of short duration was chosen for the caution alert (see Section 5.2.1). After being exposed to this sound during the training and test flights, the pilots felt that the sound was too urgent for a caution level alert. Therefore, after reviewing the available data, (Boucek, et al, 1980 and Stovner and Kelly, 1980) it is recommended that a steady-state sound be used for cautions and it is further recommended that the sound resemble the c-chord sound most commonly associated with caution level alerts.

In the final analysis, both candidate system concepts were validated as being viable for crew alerting. Since the systems differed only in their treatment of the voice system, it is important to consider the features of each method of presentation before selecting one over the other.

Voice is the recommended media of presentation when rapid response is required. Voice also permits the transfer of workload from the visual to the auditory channel (Van Cott and Kincade 1972). The system designer must be aware of the serial presentation requirements of the auditory channel, when selecting the information being presented aurally. Boucek, et al., (1980) reported a significant potential for interference between voice alerts and ATC communications when presented concurrently. These results would also be expected with other communication on the flight deck. Therefore, if voice alerts are automatically presented extreme care must be used to choose those conditions or situations in which to apply the voice alert. The condition or situation must be such that it is highly unlikely that any other communication on the flight deck is more important than informing the pilot of the problem. This criteria is met by time-critical warnings. It is therefore recommended that the System A approach be used for time-critical warnings.

The type of voice presentation in System B does not depend on a prespecified assumption of priorities but rather allows the pilot who is aware of the existing situation to select voice at the appropriate times. This type of design is suited for transferring workload between the auditory and visual channels.

6.2 TIME-CRITICAL WARNINGS

Of primary importance to time-critical warnings is the speed and accuracy of the response. Therefore, anything which increases the speed of alert detection and response without having an adverse effect on response accuracy should be considered in the system recommendations.

The results of this study indicate that the detection time measurement is very sensitive to the presentation media. The fact that there was no difference found in the mean detection time between time-critical and non-time-critical

warnings is not surprising since the attention-getting portions of both alerts are the same. For the time-critical alerts, even though they all had the same attention-getting components, a significant difference was found in the mean detection times when investigating the interaction between the presentation format and the message information type. If the detection time were a pure reaction to any alert without regard to its meaning, no difference in the treatment conditions would have been expected. However, the method by which a "detection" was determined required the pilot to make an overt action to signify detection. This action is a secondary task with regard to responding to the alert. It has been shown that as workload increases, the performance of secondary tasks changes (Rolfe, 1971). Therefore, it can be postulated that since the pilot begins processing information about the alert as soon as it occurs, the performance of the secondary task of indicating an alert detection may vary with the amount of cognitive workload (thinking) produced by the alert. If this is the case, then the data indicates that the status type alerts produce more work for the pilot especially when they are presented graphically.

The results of response performance indicates that the pilot is using urgency information to influence his response. Even though there was no difference in the detection time between the time-critical and non-time-critical warnings there was a difference in mean response time.

The content of the time-critical message is very important in terms of the amount of time taken to respond. The data indicates that guidance information facilitates the alert response. The guidance messages resulted in consistently shorter mean response times when compared to the status messages regardless of the other treatment conditions. Pilots preferred guidance messages for the time-critical situations. When guidance information is presented, the data indicates that it is most effective if it is presented graphically. Care must be used in the development of graphic presentations to insure that they are designed properly. The pilots, even though they performed better with the graphics, preferred the alphanumeric presentation. They felt that the guidance elements of the graphic display was not given enough emphasis. If this were the case, then one might expect that an improvement of the graphics would result in an even larger difference in

performance. An improvement in performance was also gained when the graphic guidance alerts were placed in the pilot's primary field of view. This provides the pilots with an efficient presentation of the information in the location which is closest to their line of sight. Finally, the addition of voice further improved the response performance.

In the tests performed for the time-critical alerts, the display was structured such that the alphanumeric message appeared on the left half of the display and the graphics on the right. In an English speaking/writing society there is a natural tendency to read from left to right, top to bottom. It was therefore expected that when the alphanumerics were combined with the graphics the pilots would see the alphanumerics first. The rationale for this placement was that if the graphic presentation was being used for the response and it was located on the left the pilot would not read the alphanumeric before he responded and there would be no performance difference between the graphic and combined formats; however, if the alphanumerics were to improve performance, putting them on the left should enhance the benefit by making it more likely that they will be read. The results indicate that including the alphanumerics on the left produces response times that are equivalent to the alphanumeric message presented by itself which are longer than a graphic presentation of guidance information. This indicates that the pilots are responding when they have enough information to permit a response no matter what the source of the information. Therefore, since the data indicated that graphic presentations are more effective, if alphanumeric information is presented, it should appear to the right of the graphics.

Finally, to summarize the pilot input concerning time-critical warnings the pilots felt that: an alert which requires a time-critical response should guide their actions with a display which is free of clutter and emphasizes the correct action; consideration should be given to using the EADI as the time-critical display since it is the primary guidance instrument; lastly, they should be given some kind of alert before the situation reached the time-critical stage.

7.0 FUTURE DIRECTIONS

The design guidelines contained in Volume II of this report are the product of several years of research directed to the improvement and standardization of flight deck alerting systems. The study has been further directed toward the display logic and display presentation functions of a crew alerting system, and operated within two functional boundaries. The investigation was bounded on one hand by a computing function which determined what alert annunciation to the pilot was necessary, and on the other by the display function which made the pilot aware of the alert.

Other parts of the total alerting system include the airplane-specific hardware which provides the multitude of information signals; the computer which assimilates the signals, processes them in a programmed manner, and decides what alerts are needed; and displays of checklist and procedural information to aid the pilot in handling the emergency. Since a systems approach was used to develop these guidelines, it is of interest to see if looking at a larger system could reveal factors which might affect the design of the alerting system. A discussion of proposed tasks follows.

7.1 ACCIDENT IMPLICATIONS ON ALERTING SYSTEM DESIGN

It is of interest investigate airplane incident and accident data to see if there are any implications on alerting system design. Such an investigation would consist of three related tasks; analysis of accident/incident data, examination of the flight deck environment, and to develop system functional design concepts which could aid the pilot in preventing or resolving emergencies.

7.1.1 EXAMINATION AND ANALYSIS OF ACCIDENT/INCIDENT DATA

Existing data bases would be analyzed to identify factors that may have contributed to aircraft accidents or incidents. The objective of the review would be to evaluate the role, if any, that the alerting system played in the accidents. The review would determine whether any dominant cause(s) exist that contribute to accidents and incidents, and to establish relationships

between the causal factors and the alerting system. The ultimate objective would be to ascertain whether the aircraft alerting system was a factor in the accident, or if with some modification could have aided the pilot in the emergency.

The review would also extract those relevant situations or failures which could create hazardous conditions for analysis in a later task.

7.1.2 EXAMINATION OF THE COCKPIT ENVIRONMENT

This task would be performed by observing commercial transport flights to record flight deck operations, procedures, and crewmember activities. The objective of the task would be to evaluate the environment in which the emergencies occur, the flight deck. The investigation would include evaluation of:

- Alert Frequency of Occurrence
- Crewmember Response(s)
- Alerting System Operation
- Flight Deck Operations and Activity
- Crewmember Responsibilities and Activity
- Crewmember Survey of System Needs

7.1.3 DEVELOPMENT OF NEW DESIGN CONCEPTS

In this task a limited number of operational situations or aircraft system failures which could possibly create hazardous conditions would be defined. These situations would be used to investigate the potential for the alerting system to monitor the aircraft for malfunctions and failures and to anticipate problems or expedite crew resolution of a problem. Particular attention would be directed to:

- Sensor Requirements
- Time-Critical Alerts and Response Requirements
- Computer Fault Diagnosis
- Computer Aided Decision Making

7.2 EVALUATE TIME-CRITICAL DISPLAY FORMATS

The current study demonstrated the feasibility of incorporating a special display for time-critical alerts. The study also pointed out that the manner in which the system information was presented to the pilot was crucial. Improperly designed displays confuse and impede pilot response, whereas properly designed displays can elicit rapid and accurate pilot response. Near-term needs for time-critical display of collision avoidance, windshear, and perhaps active control failure(s) are anticipated. Development of formats for the display of time-critical alerts is required and recommended.

7.3 INVESTIGATE INHIBIT AND PRIORITIZATION SCHEMES

The current study investigated the prioritization of alerts. A group of twenty-one pilots was asked to prioritize a list of given alerts into an order of relative urgency/importance. Two findings were obtained; effective prioritization should be flight phase adaptive, and there was a high degree of variability with which the pilots prioritized the alerts. Very little analytical or empirical work has been performed on how alerts can be prioritized; further research is necessary to develop this capability. A similiar situation exists in the development of inhibit schemes for crew alerting. Both inhibiting schemes and alert prioritization are strongly dependent on airplane design and airline operations. A study broad enough to encompass these two factors is required and recommended.

7.4 DESIGN AND EVALUATE CHECKLISTS

Methods for presenting checklists and procedures compliment any crew alerting system design. The fabrication of checklists and procedures is necessary for each airplane design, and these checklists are placarded in the flight deck and in documents available to the crew. Computer and display technology have reached the point where the manipulation and presentation of this information should be reviewed with the prospect of improving crew response to emergencies. Areas of interest in such a study include display format, checklist accessability, and computer-formulated checklists.

7.5 FLIGHT VALIDATION OF THE ALERTING SYSTEM DESIGN

Although the alerting system concepts were validated in simulation in the study, the design guidelines are essentially functional system characteristics and should be further validated through implementation into hardware and evaluated in flight tests. Such an evaluation would refine the guidelines for final implementation.

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APPENDIX A

TEST FACILITIES

A.1 BOEING'S VISUAL FLIGHT SIMULATOR

The various requirements of this study called for an easily reconfigurable facility in which several flight deck systems could be demonstrated, tested and evaluated in a realistic environment. The Kent Visual Flight Simulator at the Flight Simulation Center was chosen. Located in a flexible experimental simulation laboratory, the simulator, called the Blue Cab, was modified to represent a generic wide body cockpit configuration with working stations for a pilot and flight engineer. The pilot's main instrument panel and the flight engineer's station were designed to be reconfigurable to allow three different alerting system display configurations.

An external visual workload was provided to the pilot and flight engineer through the forward windscreens; computer controlled video and slides were used for takeoff, target location, approach and landing. The pilot and flight engineer were also presented alerting aurals, air traffic control commands, background communications, and engine and aero sounds.

The test conductor was in visual and voice contact with the pilot and flight engineer throughout the tests from his console. This console enabled the test conductor to interface directly with the main computer and control all audio and video parameters. Figure A.0-1 depicts the layout of the simulation center.

A.1.1 COCKPIT SIMULATOR

The Cab had room only for a conventional main instrument panel, standard center console, and seats for the pilot and copilot. To this cab a 58 inch extension was attached. This provided the necessary space for the flight engineer station and oculometer camera mounts, see Figures A.1.1-1 and A.1.1-2. The entire cab structure was mounted on a hydraulic platform. The cab was situated towards the front (projection screen side) of the lowered platform. This placed the pilot's eyes in an optimal relationship with respect to the hemispherical projection screen.

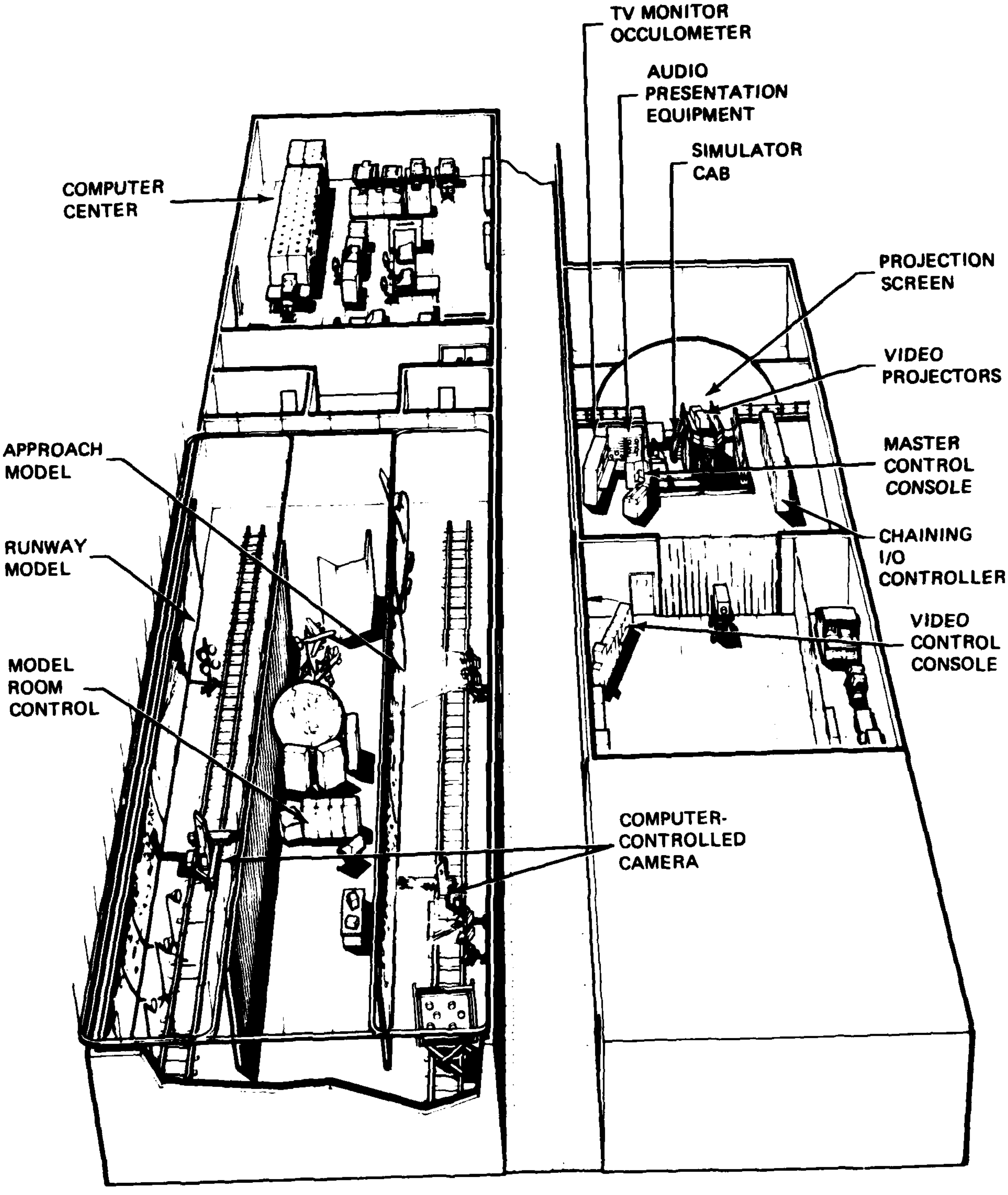
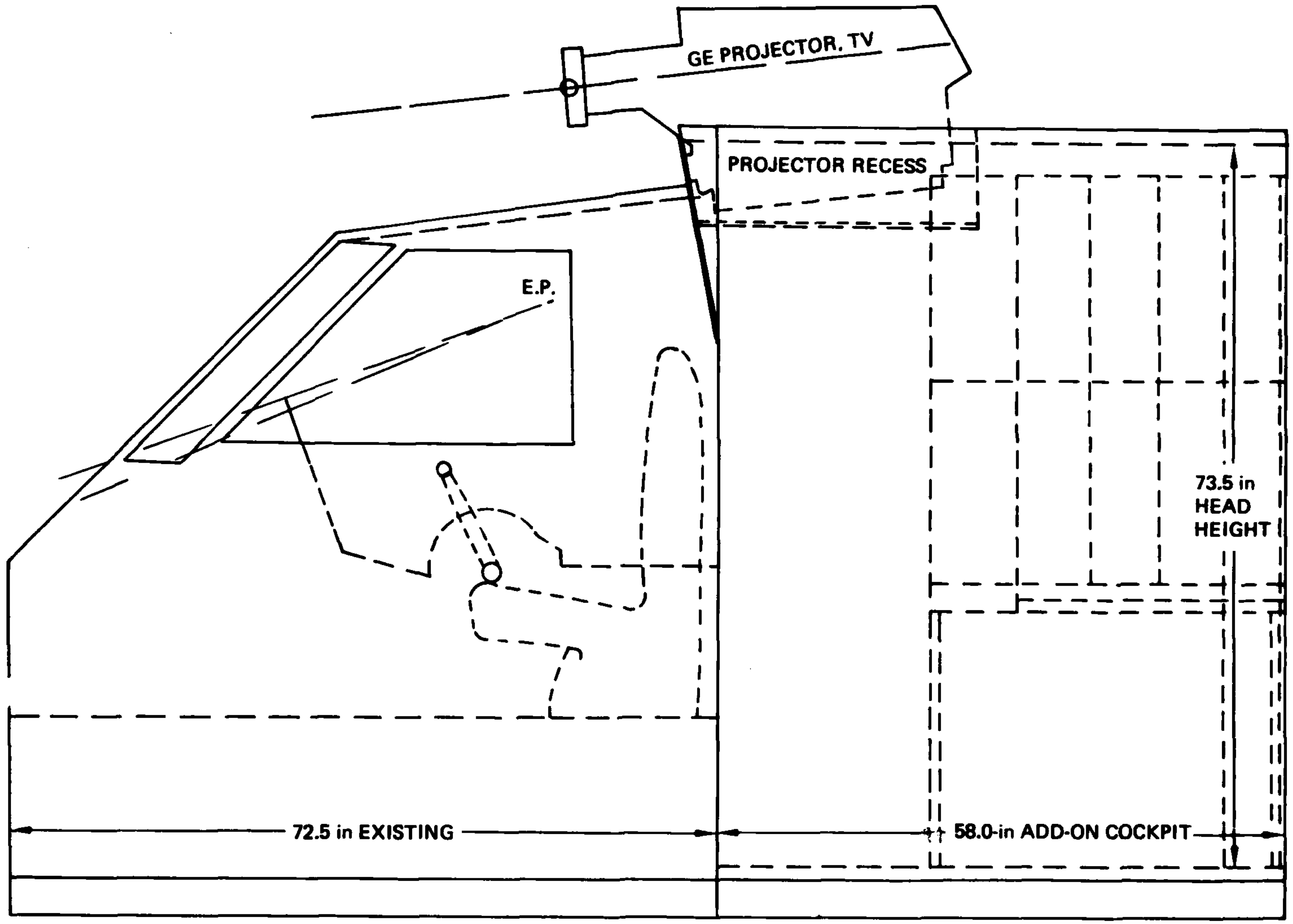


Figure A.1.0-1. Kent Visual Flight Simulation Center



SIDE VIEW

Figure A.1.1-1. Side View of Blue Cab

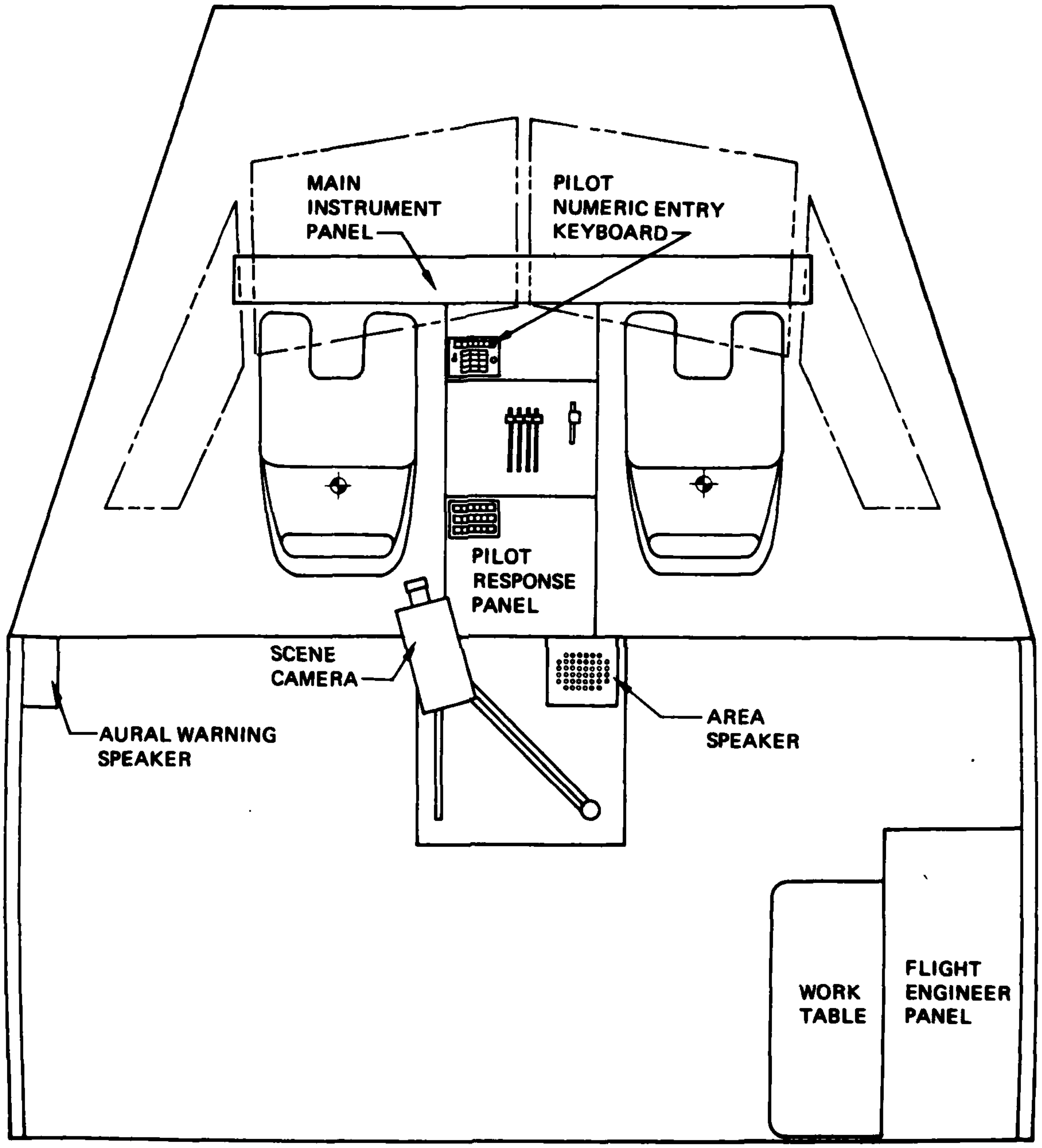


Figure A.1.1-2. Internal View of Blue Cab

A.1.2 PILOT'S INSTRUMENTATION

The existing main forward instrument panels, supporting framework, and glareshield were replaced. The replacement panels and glareshield were designed to represent a generic wide body commercial aircraft. The framework and panels were patterned to permit easy reconfiguration of instruments. Figure A.1.2-1 shows the front panel used in the Time-Critical test configuration.

The center console was modified to accept two keyboard units for pilot data entry. An overhead console containing three working, lighted engine fire handles was also added. The pilot's instrumentation consisted of raster scan CRT's, standard electro-mechanical instruments, annunciators and switches. A (9 inch) color Hitachi CRT was used for the EADI. It was driven from a Boeing built graphics generator. Two (5 inch) color Hitachi CRT's were used to present advanced and time-critical alerting messages and graphics. Both CRT's were driven by one Lexidata model 3400 color graphics generator. A (9 inch) black and white CRT was used to display engine instrument information. It was driven by a Boeing built bar graphics generator. The video generators were all driven directly from the host computer.

The servo and synchro motors of the electro-mechanical instruments were driven from a local controller. Digital information from the host computer was fed to the controller. The controller then passed it through digital to analog and digital to syncro converters. The lighted annunciators were driven by discrete output cards. Discrete input cards sampled the switches when requested by the host computer.

A.1.3 FLIGHT ENGINEER STATION

A partially active Flight Engineer (F.E.) station was installed on the right rear side wall of the cab, see Figure A.1.3-1. Six active panels were designed and installed in addition to a general alerting system annunciator panel, situation response keyboard, and numeric entry keyboard. All annunciators, switches and dials were controlled in the same manner as those on the pilot's panels. These etched panels were back-lit to simulate normal instrumentation.

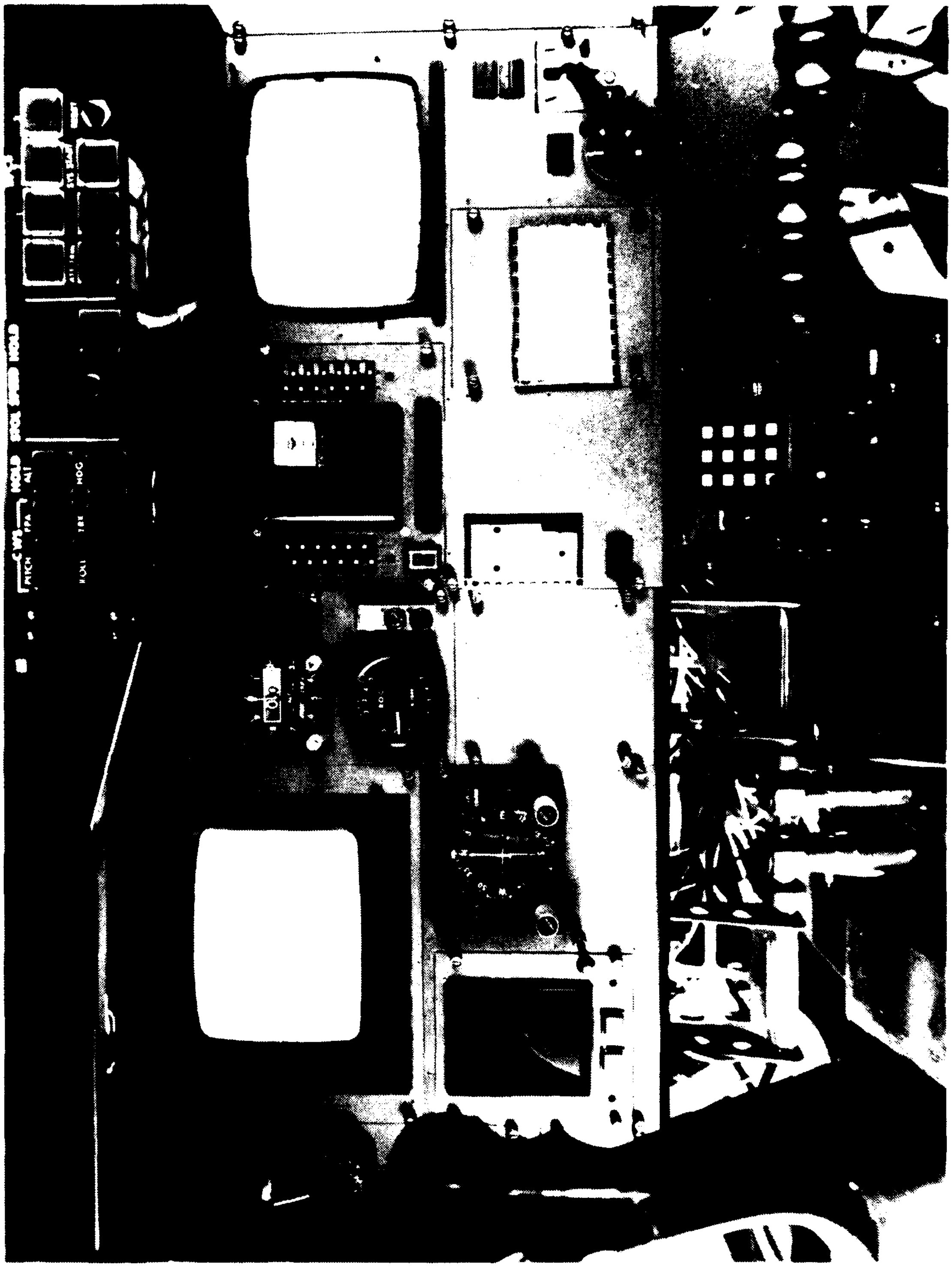


Figure A.1.2-1. Blue Cab Front Panel Layout

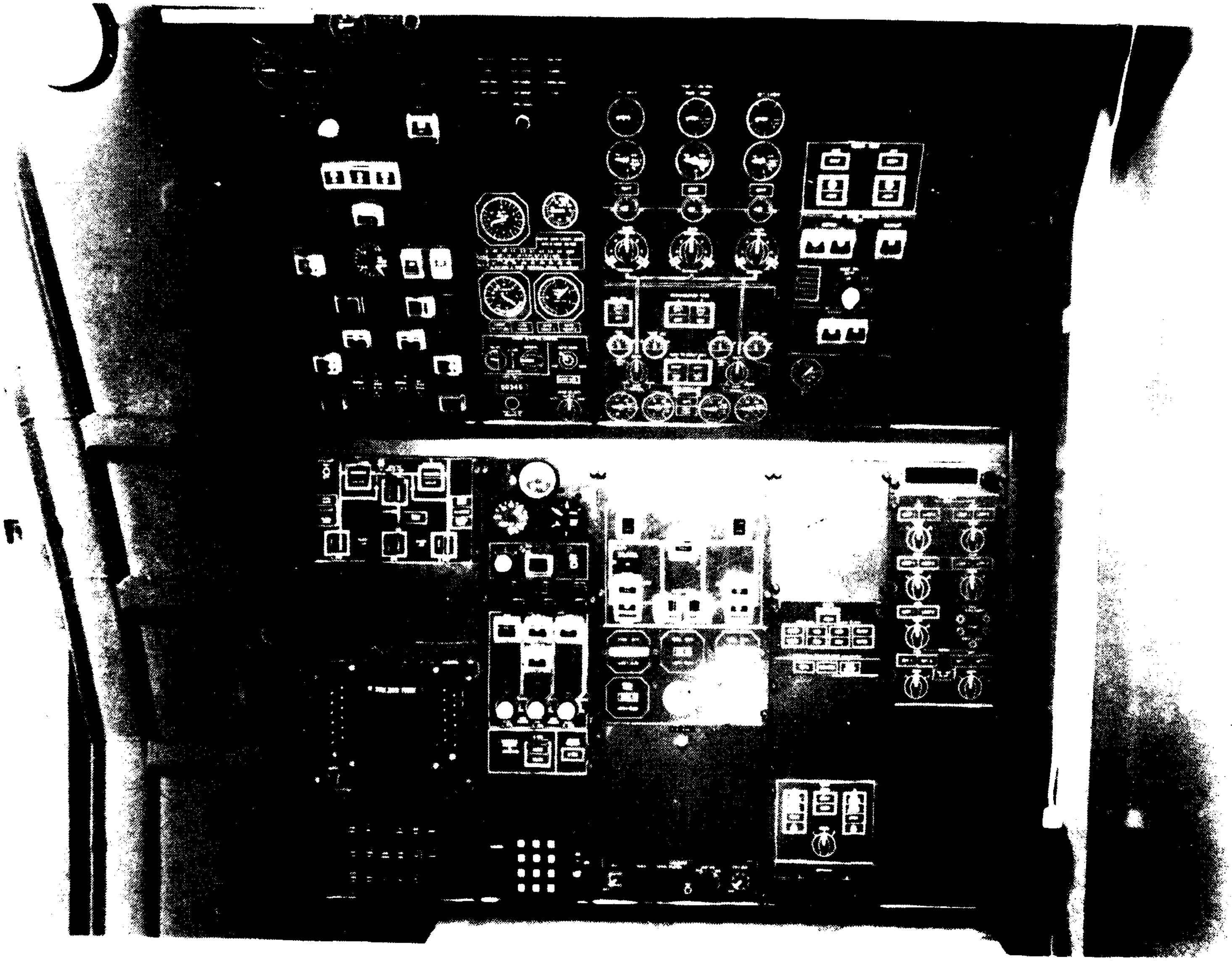


Figure A.1.3-1. Flight Engineer Station

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A.1.4 TEST CONDUCTOR CONSOLE

Located next to the cab, on the main floor of the simulation room, the test conductor console provided a good view of the projection screen, the pilot station, and the audio and video equipment. Through a terminal on the console, the test conductor controlled the simulation host computer and varied simulation parameters. An intercom system permitted communication with the host computer room, the model room, and the cab. The console layout is shown in Figure A.1.4-1.

The audio equipment rack was located next to the console. Most of the audio system controls were remoted to the console, and the close proximity of the equipment rack afforded easy visual verification of actions taken. A Z-80 microcomputer, used to control the voice alerting system, was mounted below the console. A second terminal, located to the right of the console, controlled the Z-80 and displayed voice system information.

A 19 inch black and white CRT mounted in the oculometer rack displayed the pilots instrument panel. The CRT was positioned so the test conductor could easily monitor the pilot's actions from the console.

A.1.5 HOST COMPUTER AND SIMULATION EQUIPMENT I/O

All simulation equipment, including the flight instruments, were controlled by the simulation host computer through a chaining I/O controller (or chain controller). The chain controller on instruction from the host computer passed data to selected instruments (or hardware) or retrieved data from the simulator. The chain controller also interfaced with the test conductor's console and the model room. The chain controller cycled at a rate of 2.5 to 10 milliseconds. Maximum usage brought it down to 10 milliseconds per cycle. Therefore, the maximum delta between a pilot's or F.E.'s action and the notation of that action was approximately one one-hundredth of a second.

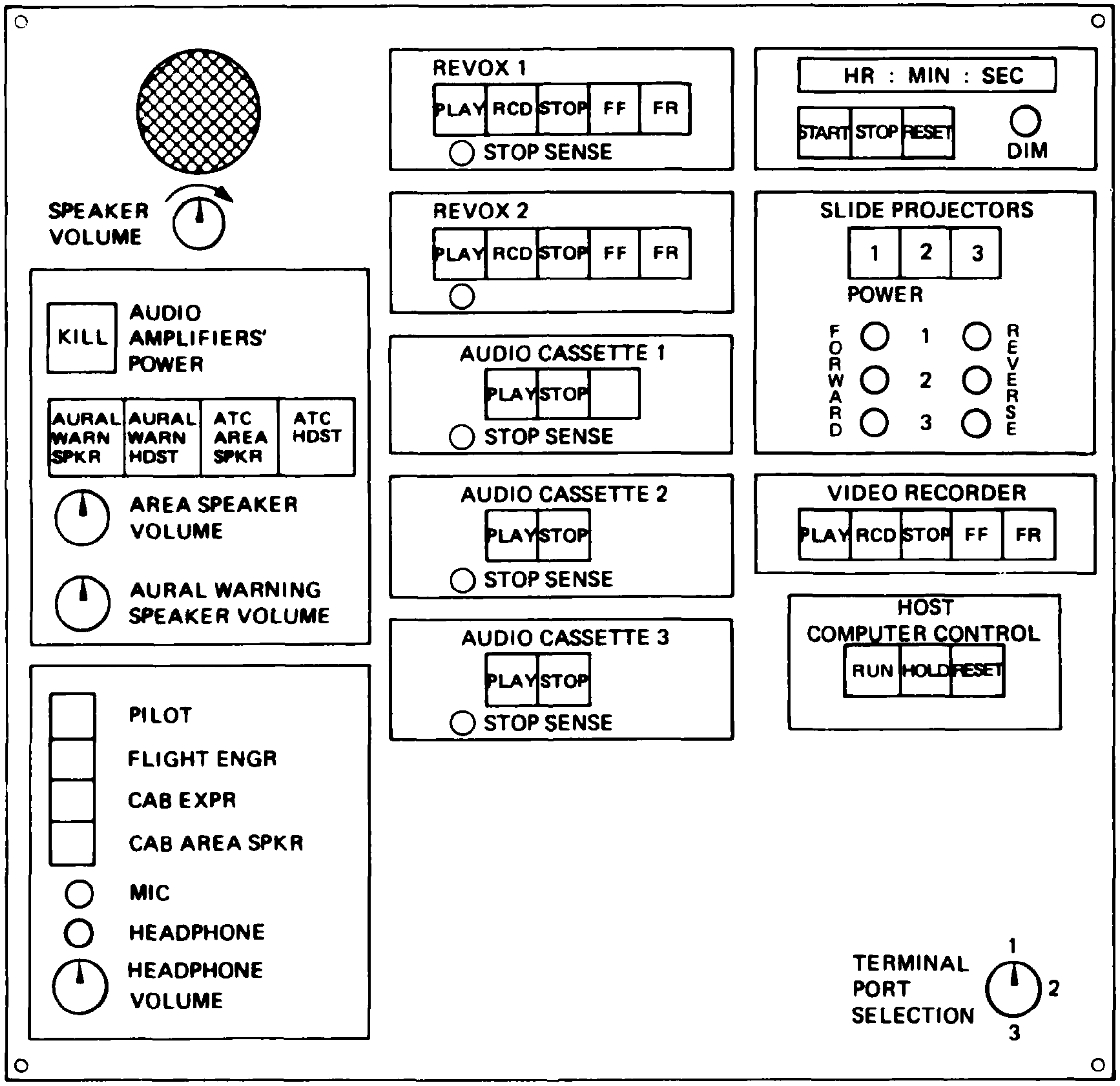


Figure A.1.4-1. Test Conductor Console Layout

A.1.6 SIMULATION HOST COMPUTER

The simulation host computer was comprised of three Varian V75 computers operating in parallel. A nine-track magnetic tape system was used to record pilot responses, flight parameters, and flight data.

A.1.7 VISUAL SYSTEM

The outside visual scene was projected on a thirty foot diameter hemispherical screen. The outside visual scene consisted of either still slide projections or a moving scene. The moving scenes were provided by a dual closed-circuit servo camera system. Each camera viewed a three-dimensional model board in the model room. The cameras were mounted on carriages that traveled over the length of the terrain boards. One board was used for take-off, final approach and landing. Initial approach was provided by the second camera and another terrain board. The scene was projected from a black and white projector that was mounted on top of the cab, directly over the pilot's head. The host computer coordinated the camera/carriage servos with the pilot's control of the airplane resulting in a realistic outside visual scene. Figure A.1.7-1 shows the layout of the video system.

For target locating and reporting workload tasks three slide projectors displayed pseudo targets on the screen. The slide projectors were advanced by the host computer but turned on and off by the test conductor at the console.

A.1.8 AUDIO SYSTEM

The audio equipment was mounted in a double width, six foot high equipment rack, see Figure A.1.8-1. Figure A.1.8-2 shows how the equipment was interconnected. Number one reel-to-reel tape player provided engine and aero noise. Number two reel-to-reel tape player provided the alerting voice recordings. The control of this player by a Z-80 micro-computer will be discussed below. Cassette recorder number one recorded the pilot's and F.E.'s voices. Cassette number two provided ATC messages. Cassette number three provided ATC background. An equalizer was used to shape the engine and aero noises to represent a heavy jet aircraft.

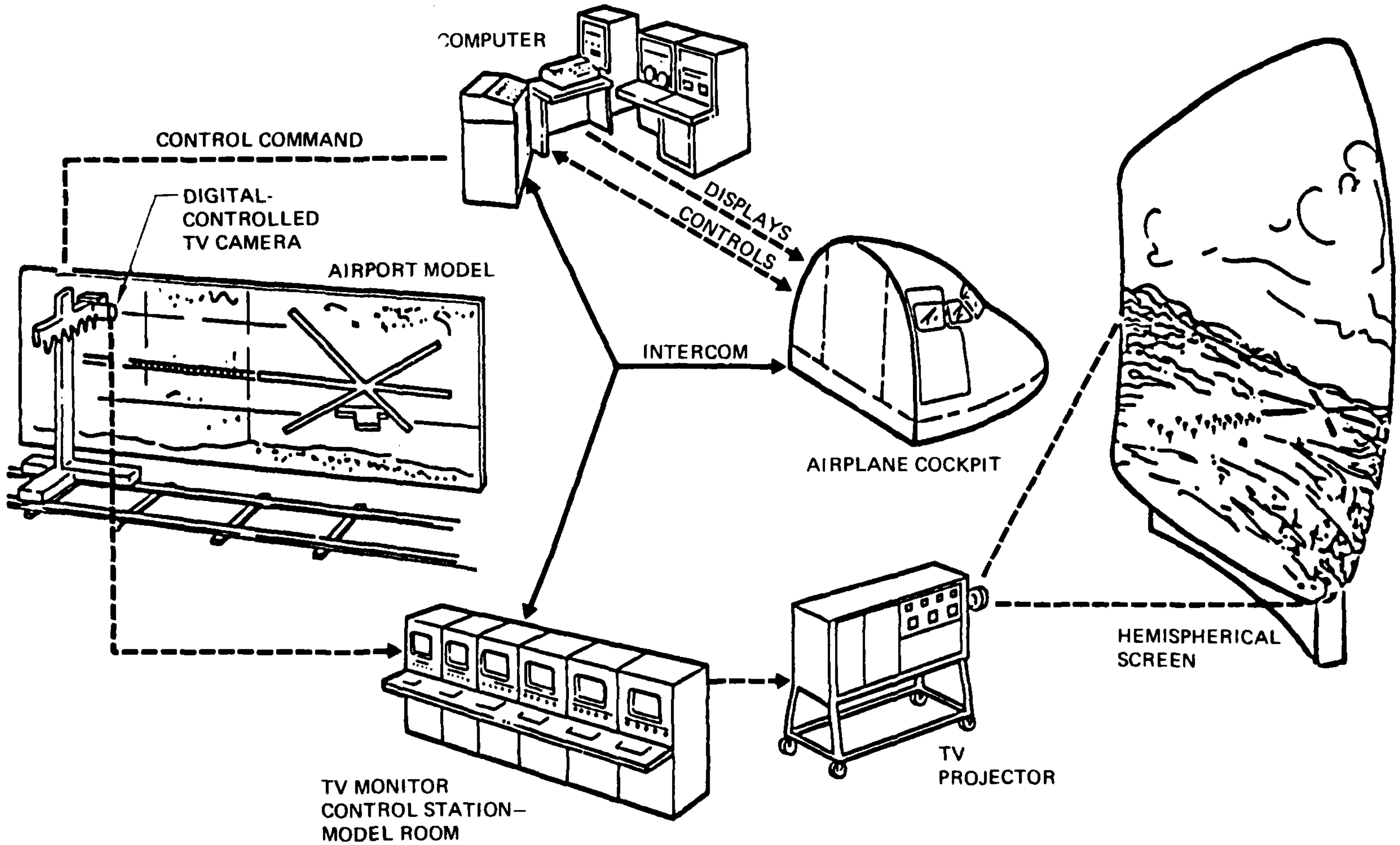


Figure A.1.7-1. Video System Layout

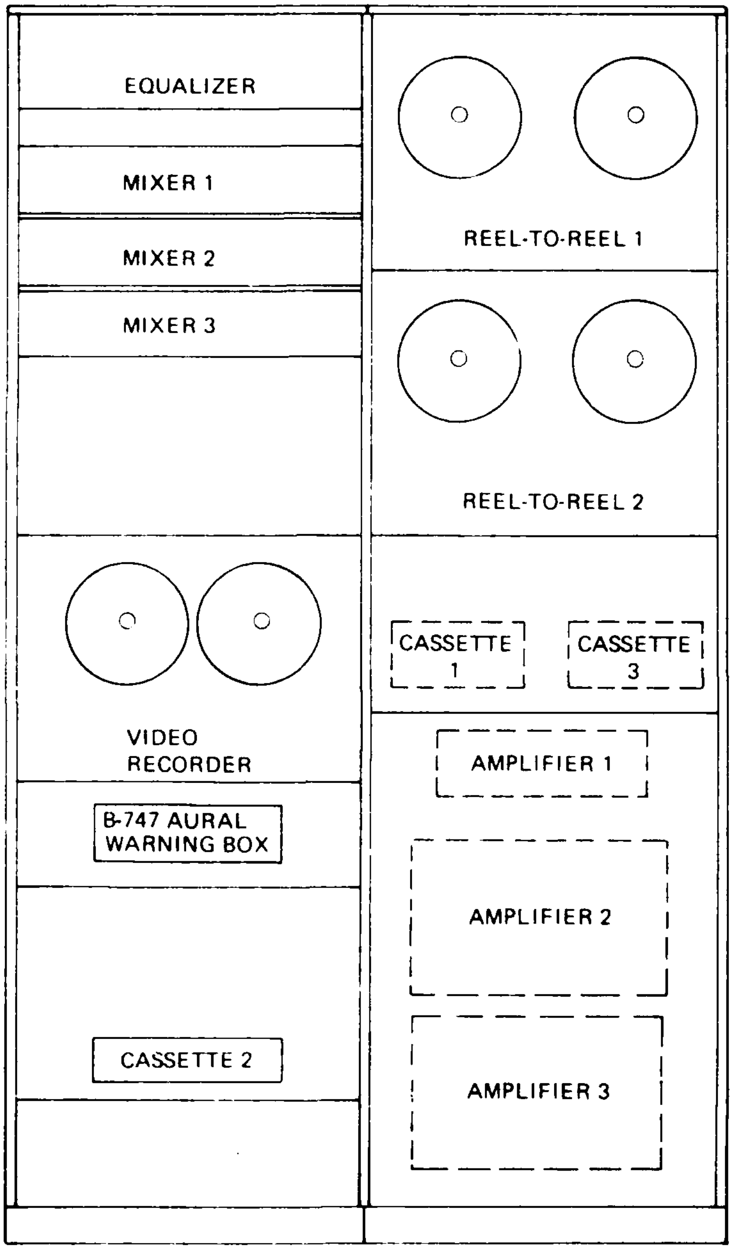


Figure A.1.8-1. Audio Equipment Rack Layout

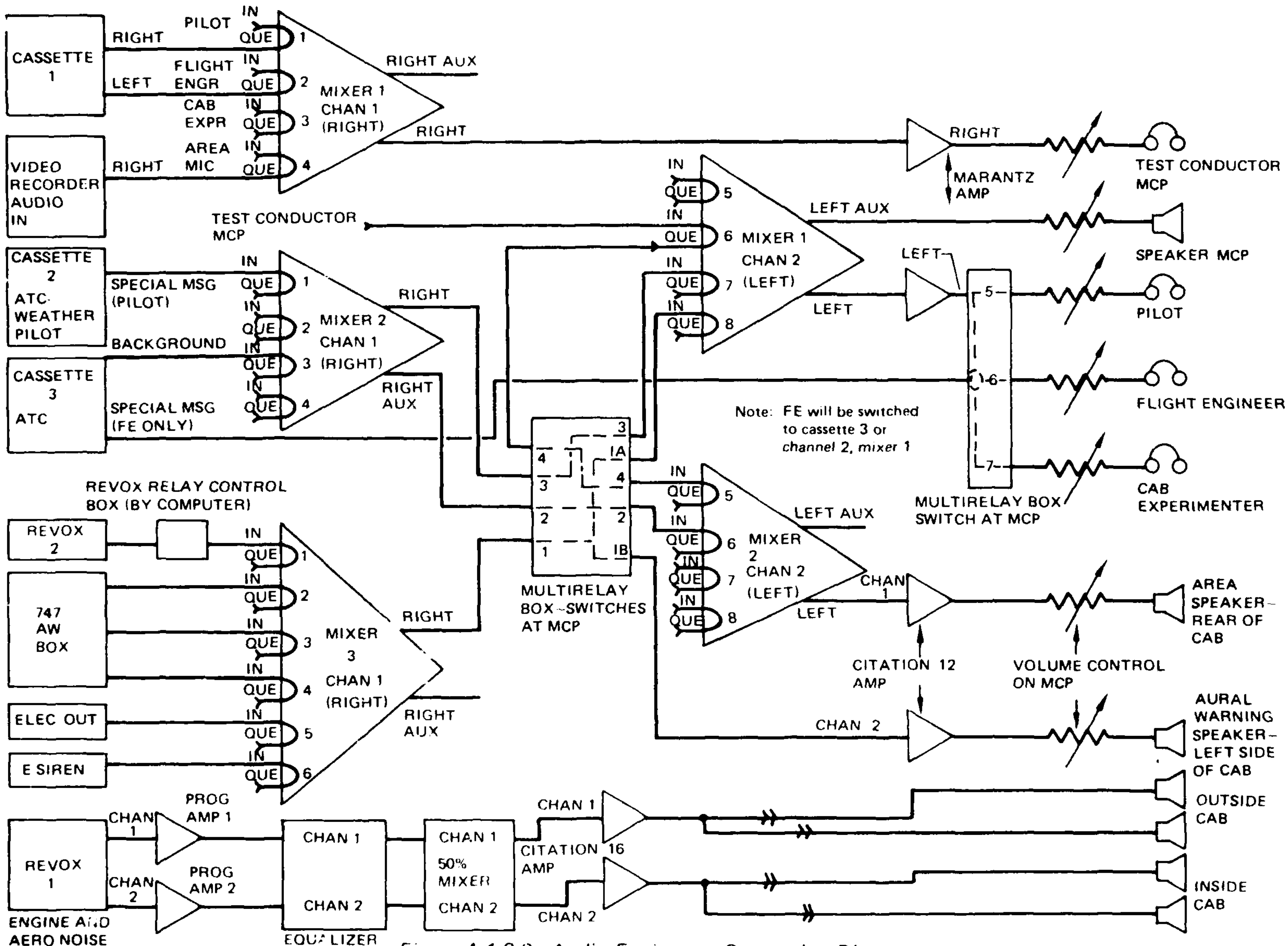


Figure A.1.8-2. Audio Equipment Connection Diagram

The host computer had direct control of thirteen discretely triggerable aural alerts. Eleven of the alerts were generated by a production B-747 aural warning box, i.e., buzzer, horn, intermittent horn, wailer, hi-chime, lo-chime, hi-lo-chime fast repeat clacker, bell and c-chord. The other two aural alerts (i.e., European siren and "electronic owl") were produced by specially designed and built circuits.

Audio mixers were used to mix the various sounds for presentation to the pilot and flight engineer. They also combined the various sounds with the pilot's and flight engineer's voices for the test conductor.

The voice alert tape player had recordings of thirty-seven different voice alerts with each alert repeated twenty times. Each alert series of twenty was separated from the adjacent alerts by a physically transparent space on the tape. The Z-80 microcomputer controlled the tape player by sensing the passage of the clear tape spaces and kept track of which message was at the playing head. The host computer would send a code to the Z-80 specifying a particular voice message, allow about 45 seconds for the Z-80 to locate the message, command the Z-80 to play the message, and then command it to stop.

A.1.9 OCULOMETER AND VIDEO MONITORING SYSTEM

The Flight Dynamics Laboratory at Wright-Patterson Air Force Base loaned Boeing their Honeywell Mark V Oculometer to be used in this study to gather data on the pilot's scan patterns. The Air Force also provided engineering support to assist in the set-up, calibration, and operation of the oculometer system.

Unfortunately, due to several hardware problems and a constrained schedule, the oculometer was not operational for use in the study. The oculometer's low light level video scene system (camera and 19" monitor) did work well, though, so the scene camera system, looking over pilot's right shoulder, was utilized to give the test conductor a good view of the pilot's actions, and the entire instrument panel. This helped the test conductor monitor the simulated flights. The output of the camera was also connected to a video tape recorder, providing the test conductor with the capability of recording an entire flight if desired.

A.2 DIGITAL EQUIPMENT TECHNOLOGY ANALYSIS CENTER (DETAC)

A.2.1 GENERAL DESCRIPTION

DETAC is a technology investigation facility used for the purpose of conducting studies and providing hands-on experience for engineers assigned to tasks associated with digital equipment. This facility was established to fulfill a requirement to upgrade the existing electronic system evaluation capabilities, particularly in the area of aircraft digital systems, inclusive of flight control computers and advanced display concepts. The facility as well as the cockpit fixture are illustrated in Figure A.2.1-1.

Aircraft that utilize several different types of digital computer systems require careful study of software structure, allocation of hardware/software function, redundancy management, etc., to obtain proper reliability and safety of flight. The DETAC system permits engineers to investigate problem areas, conduct real-time simulations, and monitor the design and integrity of vendor production hardware.

The DETAC facility has the following operational features:

- Central digital computer with a real-time operating system, 96K words of memory with memory mapping, floating-point hardware, and cache memory.
- FORTRAN IV software package.
- Interactive graphics unit with FORTRAN level software package.
- Three satellite digital computers with 32K words of memory, 512-word writable control store, and floating-point firmware package.
- High speed, party-line communications link, 500K words/sec.
- Cockpit simulation apparatus and displays.

The DETAC facility is used to support advanced commercial and military studies in digital flight controls, integrated cockpit technology, aircraft mutiplex systems, and advanced military tactical displays. Specific types of digital avionics investigations include system architecture and stability studies, digital autopilot evaluation and mechanization studies; higher-order language applications; hardware, software, firmware tradeoffs; display format studies; and software reliability and certifiability studies.

DETAC has five major elements: Central computer and peripherals, satellite computer and peripherals, interactive graphics, general input/output (I/O) hardware, and cockpit fixtures. There basic functional elements and associated equipment are shown in Figure A.2.1-1.

The Sperry Univac V76 minicomputer is general purpose and micro-programmable. A cache enhances memory access for faster operation. Three Sperry Univac V76 minicomputers provide computations and simulation support for the central computer. Peripheral support equipment includes a Dec-Writer 111 terminal, card reader, magnetic tape, cassette tape, Century Data CDS-114 disc, Infotron Vistar/GT alphanumeric display terminal, and a Varian Statos-31 printer/plotter.

Interactive computer programs define wind shears, turbulence, ILS characteristics, aircraft initial conditions, and flight-control-system parameters. Simulations of advanced flight-guidance system utilize the unique capability of DETAC to operate several computers asynchronously in parallel. Multiple computers simulate redundant avionics systems, while other computers simulate the head-up visual scene cockpit displays. Data-reduction programs plot selected simulation parameters on a Vector General display and the Statos electrostatic plotter.

This fixture consists of a wooden mockup of a three man wide body cockpit with crew seats, control mechanisms, CRT displays, instrument panel and supporting structure interfaced to the Varian computers. The DETAC cockpit can be easily reconfigured to permit the study of advanced cockpit concepts. The instrument panel consists of several color and black-and-white CRT's. A microprocessor provides a flexible interface between the cockpit controls and the satellite

Figure A.2.1-1. Digital Equipment Technology and Analysis Center (DETAC)

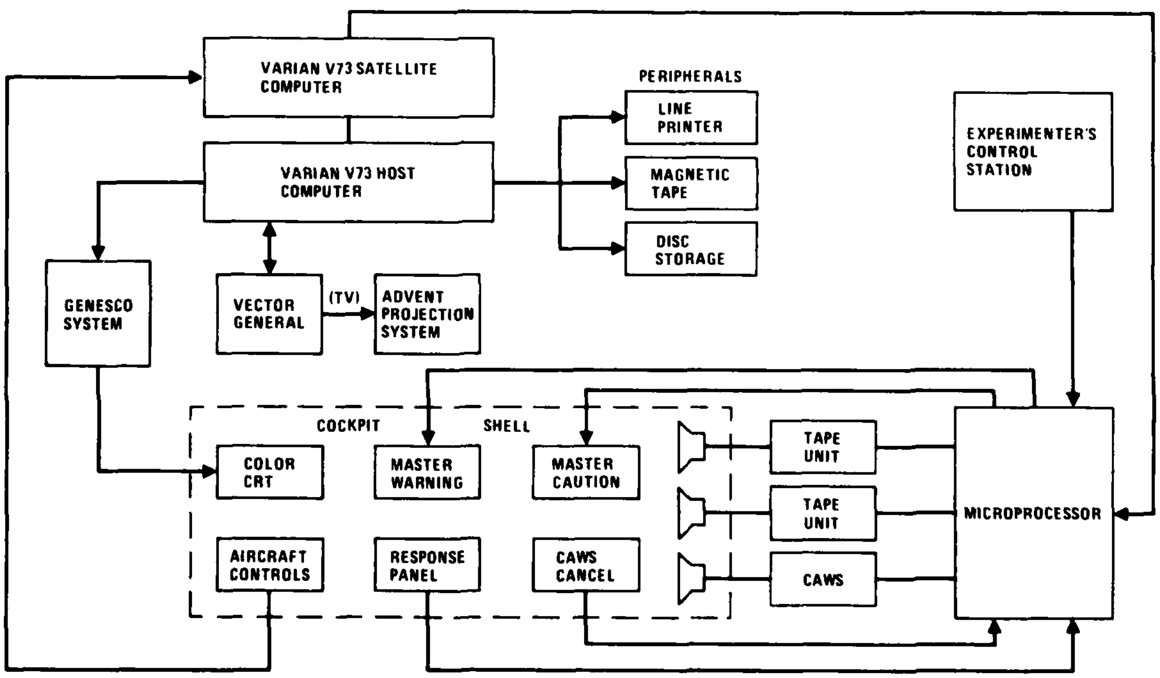


Figure A.2.2-1. DETAC Hardware Configuration for Tests III and IV of Aicraft Alerting Systems Standardization Study

computers. Head-up and external visual displays are produced by an Advent television projection system.

A.2.2 FACILITY MODIFICATIONS FOR AIRCRAFT ALERTING SYSTEM STANDARDIZATION STUDY

Several facility modifications were made prior to Phase I testing. Figure A.2.2-1 represents a schematic diagram of the hardware configuration that was used. An experiments control station was added as well as a microprocessor interface unit for activation of warning system devices in the cockpit. A prototype synthetic voice warning system was installed along with audio equipment for ambient noise simulation and ATC communications. In addition, a GENESCO color graphics system was added to drive the central caution and warning display unit. Figure A.2.2-2 illustrates the specific modifications made in the DETAC cockpit. As can be seen, a modular overhead panel was installed to accommodate lighted switches to be used for simulated fault identification and correction. Three sets of speakers were provided for the transmission of simulated ATC communications. The side panel speakers were used to introduce alert messages and the floor mounted speakers were employed to simulate ambient cockpit noise. A number of instrument panel configuration changes were also made. These modifications are shown in Figure A.2.2-3. Master warning and caution lights were added to the glareshield as well as a Central Aural Warning System cancel switch which functions to cancel and reset any on-going auditory alerts. A control display unit with its associated control keys is located at the center of the instrument panel while a hard wired annunciator matrix was installed in the Captain's primary field of view for required warnings and system status information in an operational system, the annunciator matrix would serve as a back up device to be used during control display unit failure. It is presented here for demonstration purposes and was not a part of the experimental tests. Figure A.2.2-4 shows the pilot's position relative to the two side panel speakers. As can be seen, his head is positioned between these two speakers while the ATC speaker is positioned directly above his head. The pilot's eye position corresponds roughly to the design eye reference point. Control of the aircraft is exercised by means of a side stick controller as illustrated in Figure A.2.2-5. The overhead response panel used to acknowledge fault messages as

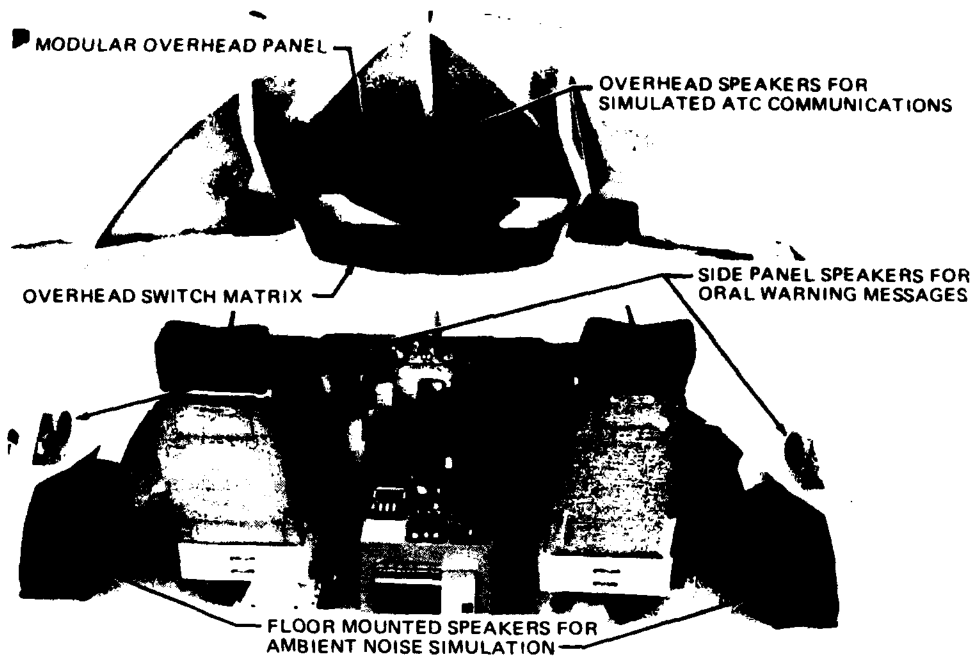


Figure A.2.2-2. Modification Made in DETAC Cockpit for Tests III and IV

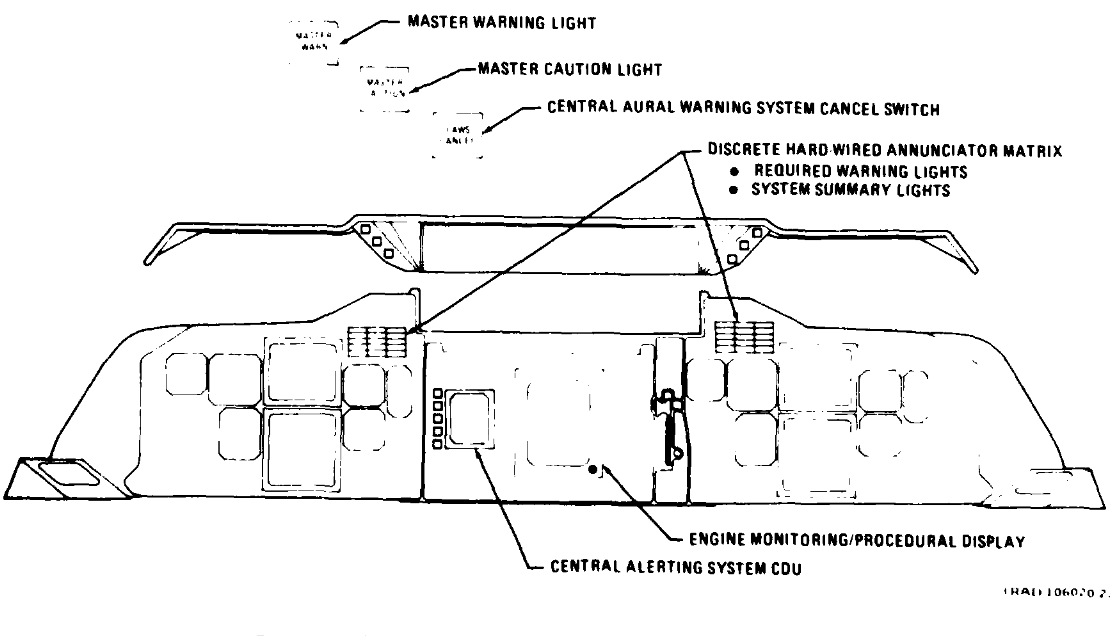


Figure A.2.2-3. Instrument Panel Configuration

Figure A.2.2-4. Pilot Position Relative to Side-Mounted Speakers

Figure A.2.2-5. Sidestick Controller, Overhead Response Panel, and Glareshield-Mounted Microphone

well as the glareshield mounted microphone used to record the pilot's verbal responses are also visible in Figure A.2.2-5. The external visual scene was generated on a computer graphics terminal and presented directly in front of the pilot on an ADVENT projection screen at a distance of approximately 15 feet. The projection screen can be seen in relation to the cockpit fixture in Figure A.2.2-6. Head-Up Display (HUD) symbology was used by the pilot for visual guidance during simulated approaches. The pilot's task was to maintain the aircraft symbol centered over the command symbol. The difficulty of this two axis tracking task could be modified by introducing various levels of turbulence. A representation of the HUD symbology as used in Phase I can be seen in Figure A.2.2-7.

As can be seen in Figure A.2.2-1, control of the experiments was maintained from a remote location within the DETAC facility. With this configuration it was possible to initiate each test trial and introduce the appropriate alert messages without having to enter the cockpit fixture. Video taping equipment was installed to record the pilot's movements and verbal responses for subsequent analysis.

Figure A.2.2-6. Advent Projection Screen in Relation to Cockpit Fixture

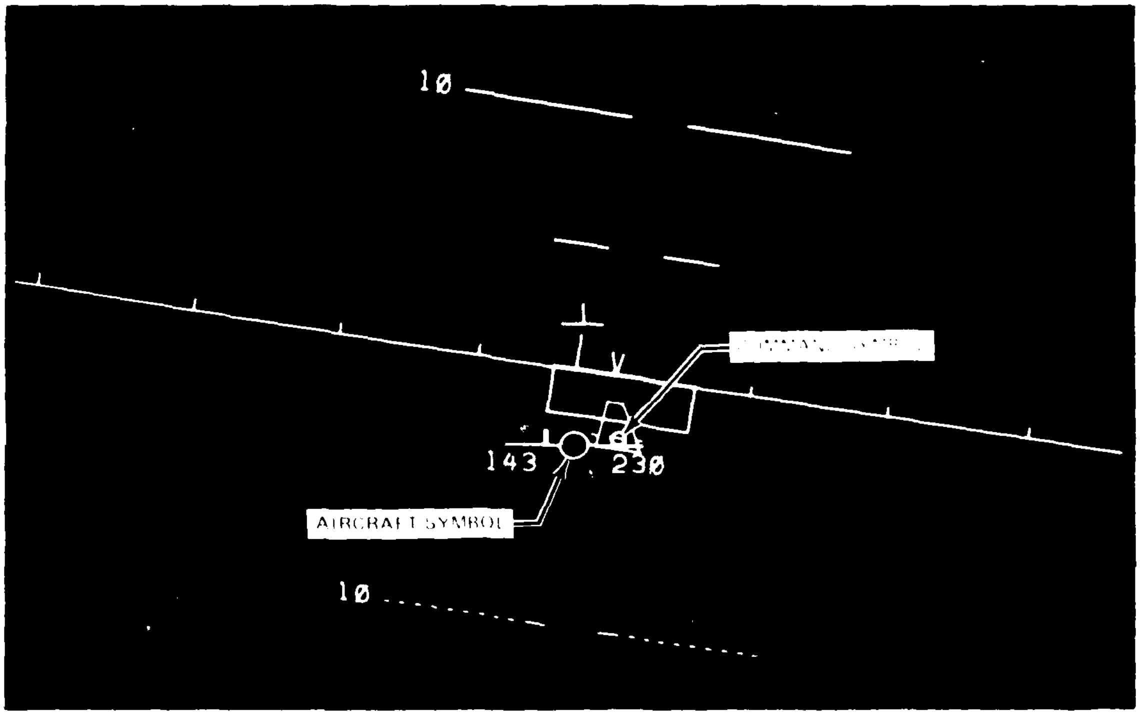
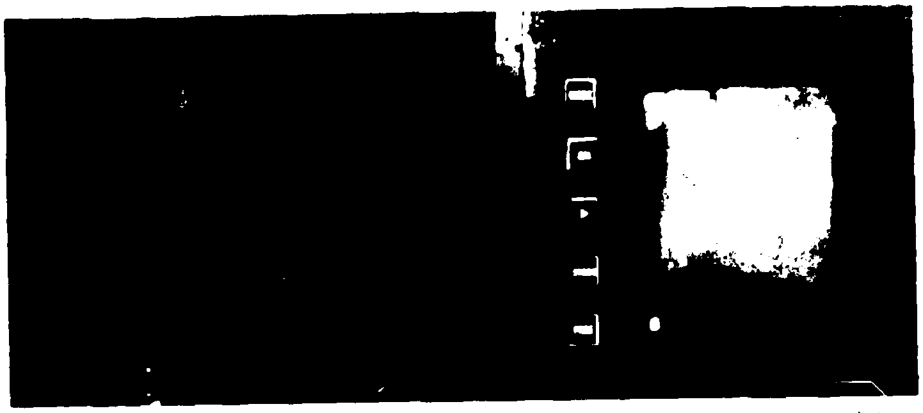


Figure A.2.2-7. HUD Symbology Used for Tests III and IV

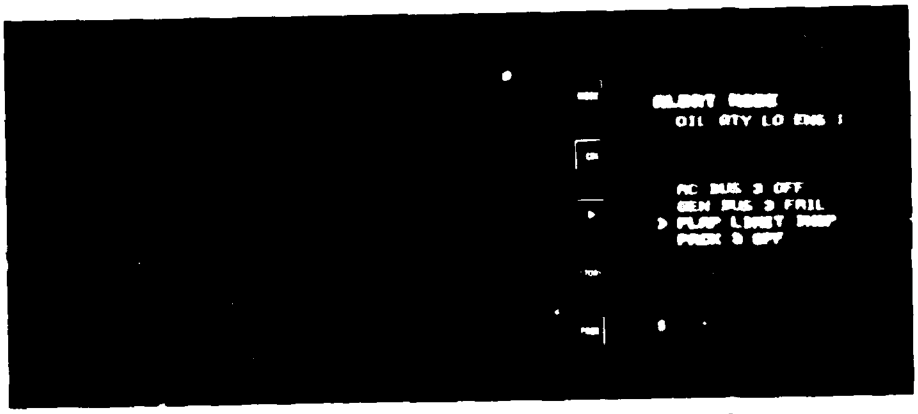
APPENDIX B

PICTORIAL REPRESENTATIONS OF INTERACTIVE CAPABILITIES OF ADVANCED ALERTING SYSTEM



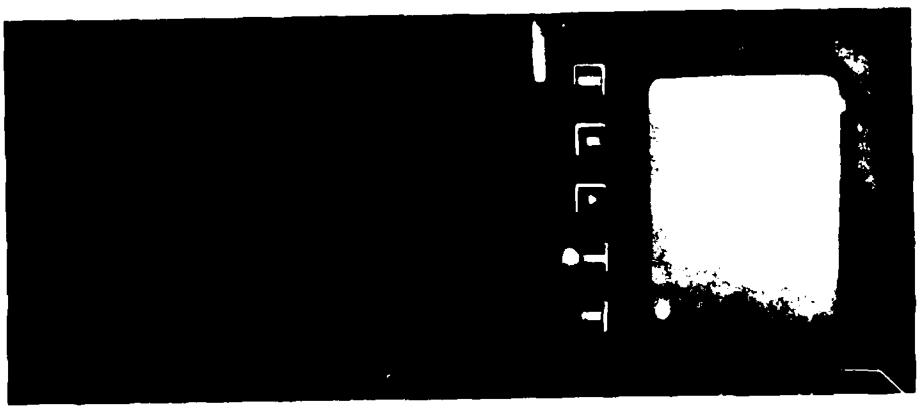
J914317

FIGURE B1 DEPRESS LINE ADVANCE KEY (WITH TRIANGULAR SYMBOL) TO BRING CURSOR DOWN TO "FLAP LIMIT INOP"



J914329

FIGURE B2 CURSOR INDEXED AT "FLAP LIMIT INOP"



J914318

FIGURE B3 DEPRESS "STORE" KEY TO PLACE MESSAGE IN MEMORY

FIGURE B4. MESSAGE ("FLAP LIMIT INOP") REVERTS TO MEMORY
Note deferred item indicator [illegible] in lower right corner)

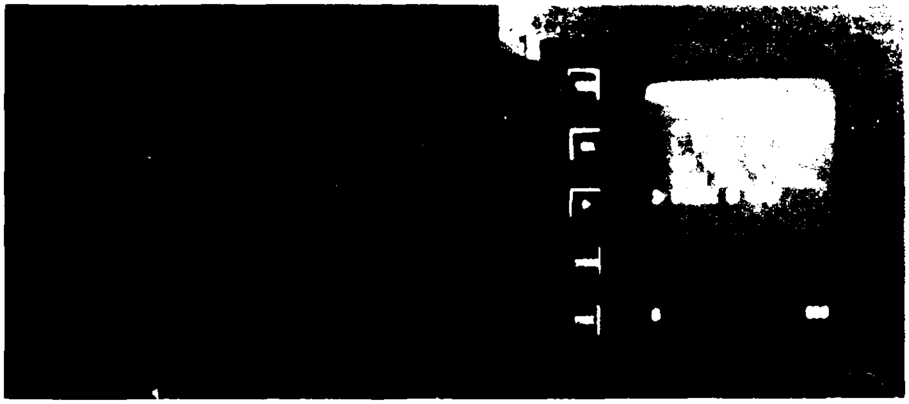


FIGURE B5. DEPRESS "MODE" KEY TO ENTER "MEMORY MODE"

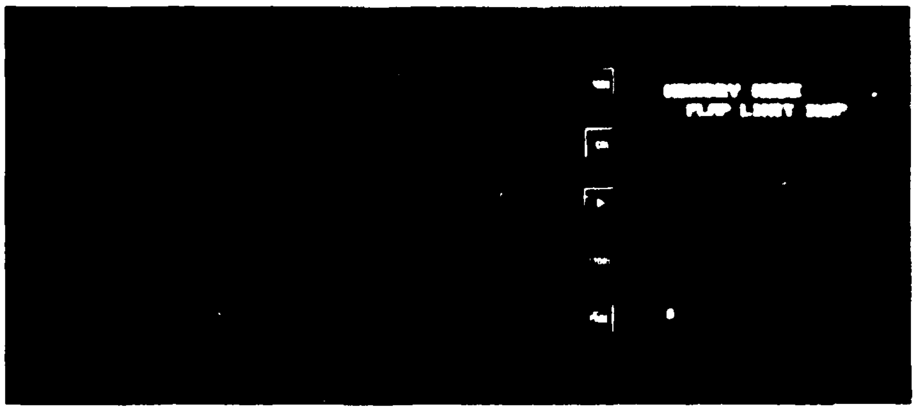


FIGURE B6. DEPRESS "MODE" KEY AGAIN TO REVERT BACK TO "ALERT MODE"

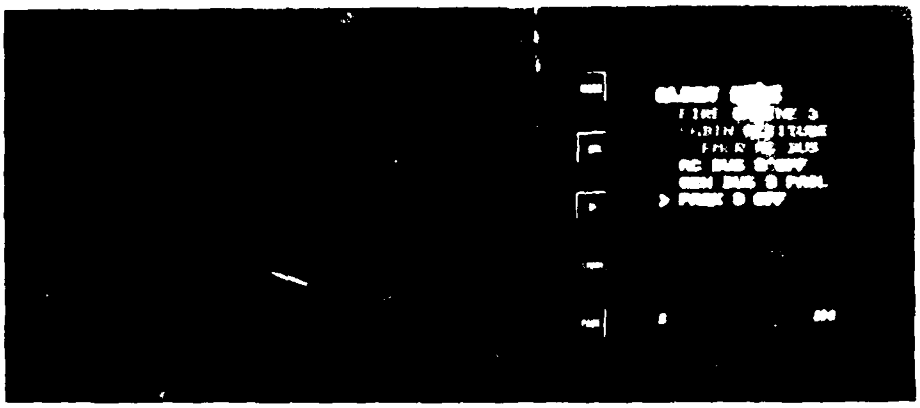


FIGURE B7. SYSTEM REVERTS BACK TO "ALERT MODE"

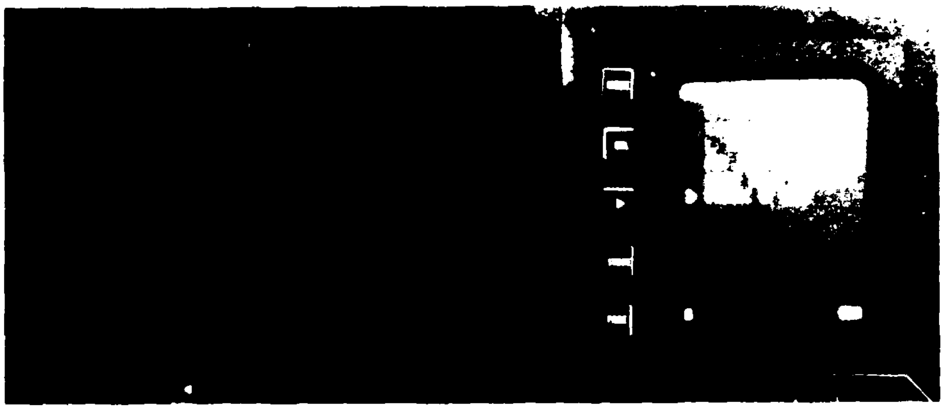


FIGURE B8 DEPRESS LINE ADVANCE KEY TO MOVE CURSOR UP TO "CABIN ALTITUDE"

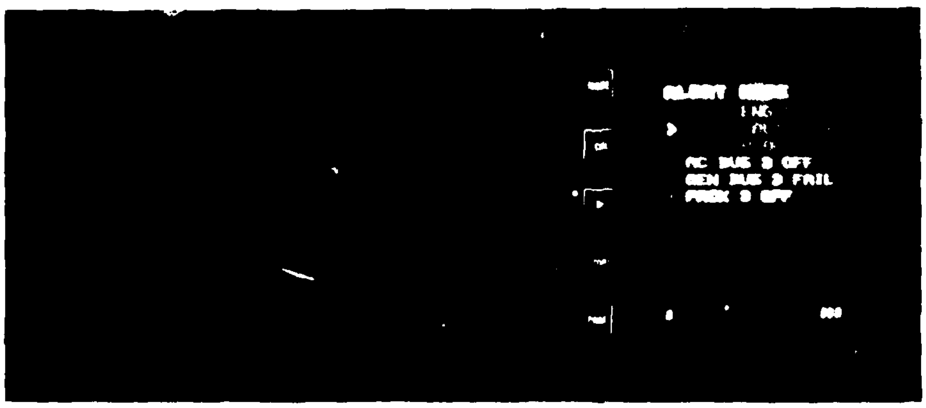
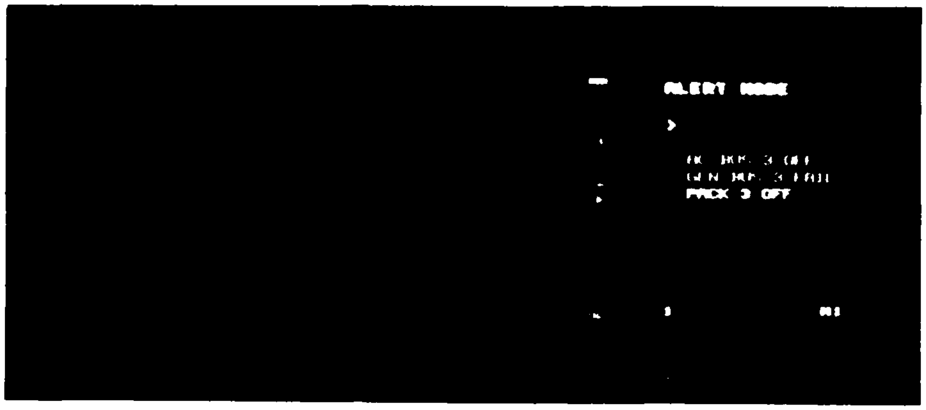
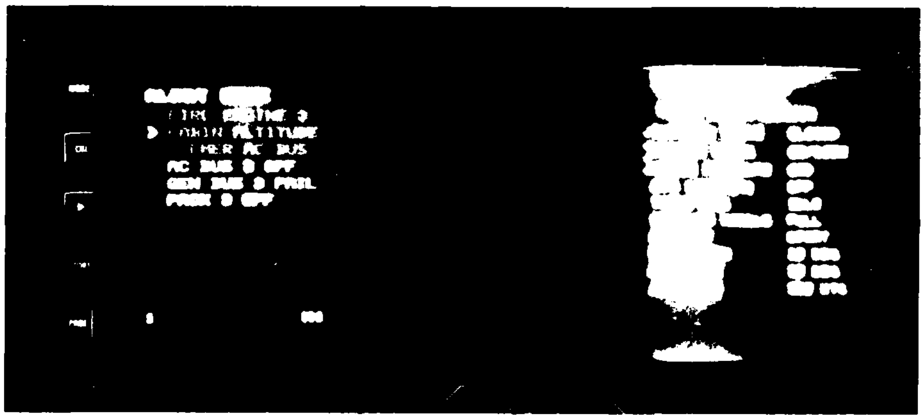


FIGURE B9. CURSOR INDEXED AT "CABIN ALTITUDE"



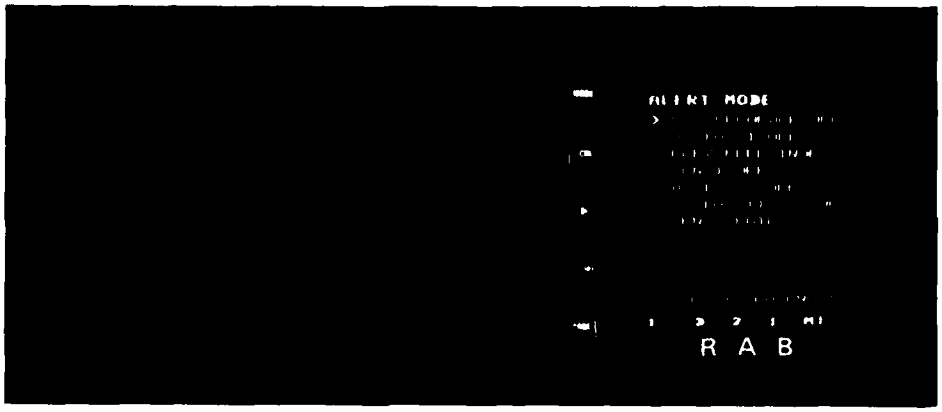
J914353

FIGURE B10. DEPRESS "CKL" KEY TO BRING UP EMERGENCY PROCEDURE CHECKLIST FOR "CABIN ALTITUDE" (RAPID DECOMPRESSION)



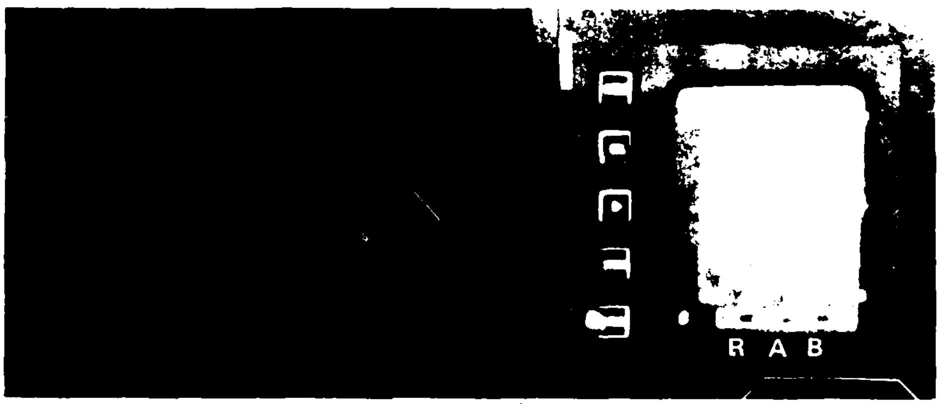
J914357

FIGURE B11. EMERGENCY PROCEDURE CHECKLIST DISPLAYED FOR "CABIN ALTITUDE" (RAPID DECOMPRESSION)



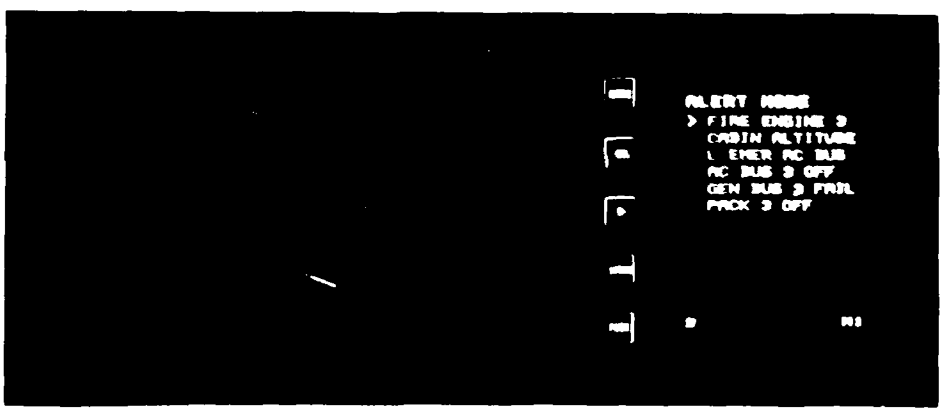
J914332

FIGURE B12. SYSTEM OVERFLOW CONDITION WITH 3 WARNINGS, 2 CAUTIONS, AND 1 ADVISORY ON PAGE 2, AS INDICATED BY COLORED BOXES AT THE BOTTOM OF SCREEN. The deferred item indicator (M1) in lower right corner indicates that one message has been stored in memory. The number (1) in lower left corner indicates that page one of the alert mode is being viewed. Note that warning messages are red, caution – amber, and advisories – blue.



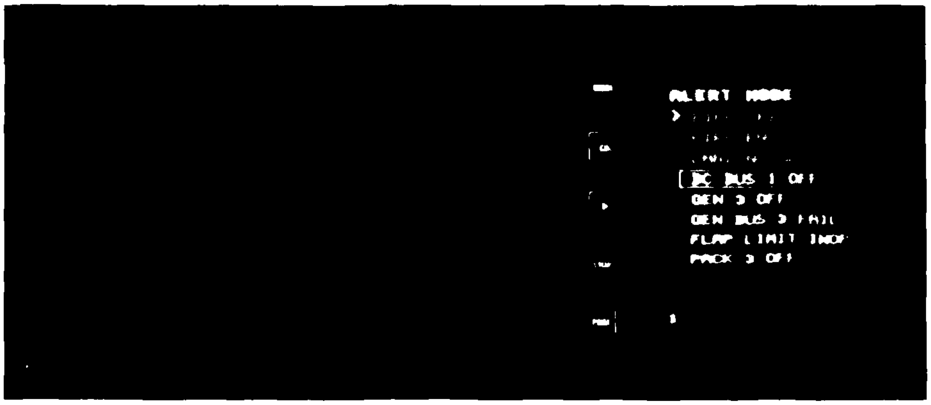
J914337

FIGURE B13. DEPRESS "PAGE" KEY TO TRANSITION FROM PAGE 1 TO PAGE 2 WHERE THE ADDITIONAL MESSAGES CAN BE VIEWED (3 WARNINGS, 2 CAUTIONS, AND 1 ADVISORY)



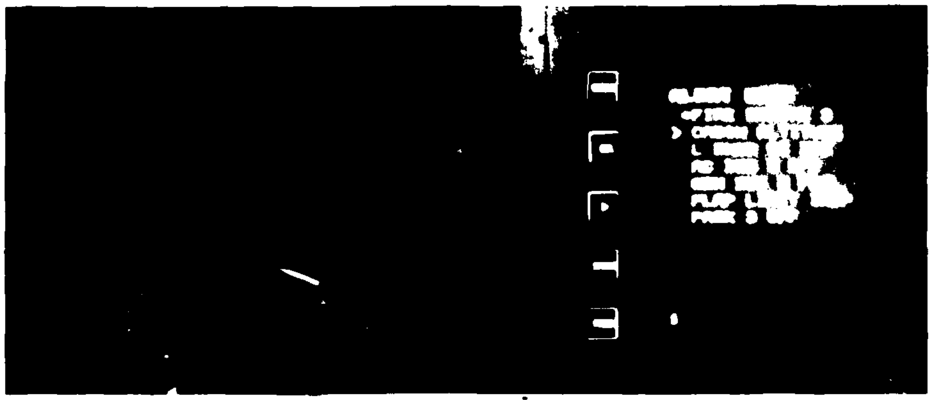
J914331

FIGURE B14. SYSTEM REVERTS TO PAGE 2. Note page indicator in lower right corner.



J914340

FIGURE B15. **BOX AROUND ALERT ("DC BUS 1 OFF") INDICATES THAT IT IS THE MOST RECENT MESSAGE'** This is method 1 for annunciating the most recent alert.



J914311

FIGURE B16. **ASTERISK (*) NEXT TO MESSAGE (FIRE ENGINE 3) INDICATES THAT IT IS THE MOST RECENT MESSAGE.** This is method 2 for annunciating the most recent alert.

APPENDIX C

FAA
AIRCRAFT ALERTING SYSTEMS STANDARDIZATION STUDY
SYSTEM COMPONENT/LOGIC EVALUATION

DEBRIEFING SUMMARY
RESULTS

ORGANIZATIONS REPRESENTED

Organization	Number of Pilots
Douglas Aircraft Company	5
Boeing Commercial Airplane Company	2
Lockheed California Company	4
Continental Airlines	6
Western Airlines	8
Total Number of Pilots Participating:	25

AIRCRAFT TYPES REPRESENTED (VEHICLE OF MOST RECENT EXPERIENCE)

Aircraft Types	Number of Pilots
DC-9	2
DC-10	6
B727	12
B747	1
L1011	4

MEAN NUMBER OF FLIGHT HOURS: 11,319

A. MASTER ALERT (WARNING AND CAUTION)

1. In the context of an advanced alerting system the master light will serve not only as a visual alert, but also as an alerting medium (not center screen message) cancellation device. In your judgment, which of the following alternatives will be most appropriate for use as visual alert?

N	
11	Split Master Light (Warning and caution lights on the same switch)
14	Separate Master Lights (Warning and caution lights on separate switches)

Can you think of any instances where separate master lights would be necessary? 10 Yes 15 No

Comments:
a) Dual warnings. (2)
b) Familiar with separate master light so prefer them. (1)
c) Different order. (1)
d) Fire warning, engine fuel shut off switches and fire handle (separate master). (1)
d) Fire warning should be delineated. (1)
e) Same system as DC-10 with engine fires. (1)
f) Dual multiple emergencies or abnormals (situation where amber condition creates an emergency condition).
g) In cancelling a caution message, a warning message could be cancelled without knowing it. (1)
h) Definite master light for different light. (1)
i) when direct sun light is on master lights. (1)
j) MEL/reminder items. (1)

B. MASTER ALERT (ADVISORY)

1. Which of the following medium do you feel would be most appropriate as master alert for advisory level information?

N		N	
4	Master light	2	Master light and voice
0	Discrete tone	12	Master light and flashing box
0	Voice	2	Tone and flashing box
3	Flashing box around most recent message	1	Other
1	Master light and tone		

2. Advisory information display. Which of the following do you feel is the most appropriate means by which advisory level information should be displayed?

N	
0	Voice
23	Alpha numeric display
2	Voice plus alpha numeric dipslay
0	Other

C. STORE/RECALL

1. Two methods are presently available for storing messages and recalling them from memory. A total store/recall capability would be desirable as it would reduce the interactive time requirements of the system. Can you foresee any situations where a selective store/recall capability would be desirable or necessary?

<u>Comments</u>:
a) When phase of flight or problems are of different order of importance. (1)
b) Should be capable of both, so low priority items can be delayed. (1)
c) Multiple sector flights where continuation using redundant system to increase departure reliability. (1)
d) Should be capable of both (avoid unwanted messages but also provide a full message capability. (2)
e) When problem display has been attended to with all procedures--but problem can't be solved it should be moved to "store" or reduced to "advisory only" because no other action can be taken. (1)
f) MEL items/low priority items. (1)
g) Should have priority built into it on importance of certain critical systems of the airplane. (1)
h) More options available to tailor unit to respective airlines checklist procedures. (1)

2. Overall, which feature would you prefer?

N	
8	Total store/recall
3	Selective store/recall
14	Combination of total and selective store/recall
0	Other

a) Automatically goes into store after all "checklist" items have been completed. (1)
b) Flexability. (1)
c) Total store recall should be minimum required but some situation select recall could be used. (1)

D. PROCEDURAL/CHECKLIST INFORMATION

How effective was the presentation of procedural information that was demonstrated?

N	
7	Excellent - No changes recommended
16	Good - Minor changes beneficial
2	Fair - Minor changes recommended
0	Poor - Major changes recommended
0	Very Poor - Major changes necessary

Please describe any changes or recommendations you feel should be made regarding procedural information.

Comments:
a) CRT was not readable. (1)
b) Checklist automatically displayed for all warnings. (1)
c) Two warnings occurred at the same time--highest priority displayed first. (1)
d) Item being accomplished could be flashed or boxed. (1)
e) Current checklists utilize a logic flow pattern where choices are offered which could be incorporated. (1)
f) Procedural development of checklist response by either asterisk movement or line cancellation. (1)
g) System of checking or noting each item on list as it is accomplished. (1)
h) System would have to be developed to avoid aircraft action without thought--if it is required for flight-performance consideration. (1)
i) Critical items should be isolated from non-critical data. (1)
j) Have display uncluttered of all but critical items. (1)
k) Procedure items should be color coded the same as information. (1)
l) Some method to cross through each step as completed. (1)
m) Immediate action items should be in bold face presentation. (1)
n) Priority could be beened to be established on items that could or would selectively be stored--as immediate and secondary actions are completed itsm should be automatically stored. (1)
o) Slightly larger screen would be easier to read. (1)
p) The checklist should provide interaction where possible when the steps of the check are completed. (1)
q) The checklist information will disappear when check off or completed--?
r) Color should be employed using the same priority method as master light--include cruise data callup and system trouble shooting procedures. (1)
s) Color dots could be used to emphasize items completed or items to be completed as well. (1)

E. RANK THE FOLLOWING OPTIONS FOR ATTENUATION/CANCELLATION OF AURAL ALERTS

Number of #1 Rankings		
2	a)	Automatic volume reduction after a fixed number of repetitions.
0	b)	Manual volume reduction.
4	c)	Automatic cancellation after a fixed number of repetitions.
19	d)	Manual cancellation with automatic cancellation after problem corrected.

Consider the option that you rated most highly. Briefly explain why.

1. Automatic volume reduction after a fixed number of repetitions.

Comments:
a) Manual cancellation of item is done without conscious thought. (1)
b) Only the most critical warnings should be aural and then only for fixed number of repetitions due to the numerous things going on in the cockpit. (1)

2. Automatic cancellation after a fixed number of repetitions.

Comments:
a) Reduce the number of action required by aircrew. During an emergency also extraneous sounds in the cockpit are distracting once emergency has been identified. (1)
b) Gives the crew the information they are required to perform an action in order to answer a computer. (1)
c) Least distracting for pilot flying the aircraft--should also include a automatic volume reduction after first alert. (1)

3. Manual cancellation with automatic cancellation after problem corrected.

Comments:
a) Aural warnings can be annoying if continues--we only need a attention getter--should be able to be silenced manually. (1)
b) Make it possible to cancel aural alert to avoid distraction once problem acknowledged--if corrected itself as with power shift then would want auto cancellation. (1)
c) Terminate voice as soon as possible because it interferes with ATC communication. (1)
d) Any alert should require positive action by the pilot to cancel problem signal. (1)
e) Places pilot in the decision-making process to think about the problem with time left up to him. (3)
f) Gives flexibility of manual with automatic feature. (1)
g) Consider inhibition warnings during critical take off area. (1)
h) Enables retention as long as desired and maybe cancelled at discretion. (2)

i) Once Attention is drawn to the item and acknowledged, the aural only provides a distraction. (2)
j) Pilot should cancel warning, because auto cancel could cause signal to be missed. (1)
k) Requires a positive action thereby assuring corrective action of the fault (after corrected it should be dropped). (1)
l) Because he's use to it. (2)
m) During many phases of flight master warning and caution alerts would have to wait for flight maneuvering to be completed. (1)
n) ATC can override many alerts--distraction of this type in critical phase or flight situation must be manually cancellable under other conditions auto cancellation is desirable.
o) With automatic cancellation with alot of messages one could think the problem was solved if he no longer heard alerts after respond to problem annoying to have verbal non- cancelling message continue. (1)

F. VISUAL MESSAGE SYNTAX

MIL-STD-411D recommends the following format for verbal alert messages:

General Heading	Specific Subsystem Or Location	Nature of Emergency
Engine	Number 1	Hot

Which format do you feel would be most appropriate for visual messages?

N		
20	a)	General Heading - Subsystem/Location - Nature of Emergency/ Condition
3	b)	Nature of Emergency/Condition - General Heading - Subsystem/Location
2	c)	Other

Please explain the rationale behind your selection.

Comments:
a) Data presented needs to be in logical sequence for the pilot. (1)
b) Nature of the problem (first), where the problem is (second), and delay the third. (1)
c) Identify a problem, the system, the location, and logical progression of what to do. (1)
d) Both depending upon the item--fire Engine No. 1, oil pressure low. (1)
e) Identify item priority to declaring the nature of the emergency. (1)
f) General/subsystem/location, nature/condition. (1)
g) Emergency situation--nature of emergency--then identify correct engine or whatever. (1)
h) Nature of emergency most important. (1)
i) Delete/? of emergency (Engine No. 1) associated instruments would indicate problem. (1)

G. VOICE ALERT

It has been suggested that the words "warning" and "caution" may be more effective than auditory tones as precursors to corresponding alert messages. Which of these alternatives do you feel would be most appropriate?

N	
15	Words better than tones as master alert
9	Tones better than words as master alert
1	No difference

Please explain the rationale behind your selection.

1. Words better than tone as attenson.

Comments:
- a) With CRTs fewer categories of information would have to be remembered. (1)
- b) Excessive number of warning sounds presently incorporated. (4)
- c) Proliferation of tones becomes a confusion factor. (1)
- d) Word warning could increase set response action especially when tired. (1)
- e) Need to incorporate state-of-the-arts technology, but also accommodate progressive flight crew transition. (1)
- f) Noise level in the flight station could mask the aural level.
- g) Don't have to memorize tones--under stress they (tones) can be confused. (1)
- h) With all the tones already present, word would be better. (3)
- i) Should have a tone associated with a word. (1)
- j) No translation required, therefore no misunderstanding. (1)
- k) Quicker recognition. (1)
- l) Takes the guess work out. (1)
- m) Word serves a double purpose of attention and acknowledgement of problem. (1)

2. Tones better than words as master alert.

Comments:
- a) Tendency to "filter" voice to hear what is needed at the time. (1)
- b) Easier recognized if the number of tones are kept to a minimum--there is too much conversation in cockpit already. (1)
- c) Distinct tone or sound may be more recognizable under interfering conditions. (1)
- d) Words O.K. for low level problems, but for attention grabbing tasks a "noise" is superior. (1)
- e) Cockpit is continually full of radio chatter, so appropriate tone warning would be most useful. (1)
- f) Tones are adequate--but words would be better--but don't need them. (1)

H. SEQUENCING OF MULTIPLE VERBAL ALERTS

Rank the following options for sequencing of multiple verbal alerts. If you can suggest a viable alternative, please describe it briefly in the space provided and rank it accordingly.

Number of #1 Rankings		
8	a)	Prioritize messages and annunciate only the most severe problem. Annunciate subsequent message(s) only after the previous one has been corrected or somehow accommodated.
0	b)	Introduce each message for a fixed number of repetitions, cancel it and introduce the next one. This would also require prioritization within gross alert category.
14	c)	Introduce the message "multiple alerts" and direct flight crew attention to central display unit for specific fault messages.
3	d)	Other

4. Other

Comments:
a) Introduce all new messages and prioritize with a flashing box, which would move on by priority.
b) Boxing will draw the operators attention to the most serious and still allow total view of the problem. (1)
c) Voice alerts cannot be utilized on multiple alerts--can only do one at a time.

I. GENERAL COMMENTS

1. Chevron should advance with line as messages occur. (3)

2. Possible indent caution and advisories. (1)

3. Procedure might come on automatically. (1)

4. Be sure you don't add to the crew workload with a bunch of new buttons, etc. (1)

5. There are too many aural alerts (tones) in conventional cockpits. (4)

6. There is an excessive number of nuisance alerts and false warnings in the cockpit today. (1)

7. The alerting system needs to be centralized in the cockpit. (1)

8. It might be appropriate to indent cautions and advisories so a loss would not cause a loss of the pilot ability to differentiate time essential from low priority alerts. (1)

9. With a prioritization system, procedural information might come on automatically for the most severe alert. (7)

10. Display major problem and subsidiary problems indented below it. (1)

11. Simplicity and reliability are the most important characteristics of the alerting system. (1)

12. New or most recent message could be annunciated by increasing its intensity on the visual display unit.

13. A back up CRT could be used for normal operation checklists as well as emergency procedures. (1)

14. Lack of pilot agreement on alert prioritization and inhibit logic will serve to highlight the need for a good prioritization and inhibit system. If system designers have trouble prioritization alerts when gathered around a meeting table, it may be unrealistic to expect pilots to prioritize and act on alerts during a multiple failure situation, characterized by high levels of workload, stress and confusion. (1)

APPENDIX D

FAA
ALERTING SYSTEM STANDARDIZATION STUDY
SYSTEM COMPONENT EVALUATION
DEBRIEFING QUESTIONNAIRE
RESULTS

ORGANIZATION REPRESENTED

Organization	N
Douglas Aircraft Company	4
Boeing Commercial Airplane Company	2
Lockheed California Company	4
Continental Airlines	4
Western Airlines	3
Total Number of Pilots Responding	13

AIRCRAFT TYPE MOST RECENTLY EXPERIENCED WITH:

Aircraft Type	N
DC-9	4
DC-10	1
B727	8
L-1011	4

MEAN NUMBER OF FLIGHT HOURS: 13,019

FAA
AIRCRAFT ALERTING SYSTEM STANDARDIZATION STUDY
SYSTEM COMPONENT EVALUATION

DEBRIEFING QUESTIONNAIRE

NAME: ______________________________ DATE: ______________________________

ORGANIZATION REPRESENTED: ______________________________

AIRCRAFT TYPE MOST RECENTLY EXPERIENCED WITH:

DC-10	B-707	B-737	L-1011
DC-9	B-727	B-747	OTHER

NUMBER OF FLIGHT HOURS: ____________________

MAIL COMPLETED QUESTIONNAIRE TO:

David Po-Chedley
Mail Code 35-36
Douglas Aircraft Co.
3855 Lakewood Blvd.
Long Beach, CA 90846

VISUAL ALERTING SYSTEM
DEBRIEFING QUESTIONNAIRE

Key:

Candidate Concepts To Be Evaluated:

1. Chronology within color (CC): New message appears at the bottom of its alert group.

2. Reverse Chronology within color (RCC): New message appears at the top of its alert group.

3. Priority (P): New message appears at the pre-determined location within its alert group depending on its priority level.

4. Basic Chronology (BC): Most recent message appears at the top of the list, regardless of color or specific priority level.

Scoring Options:

1. Excellent - No changes recommended.
2. Good - Minor changes beneficial.
3. Fair - Minor changes recommended.
4. Poor - Major changes recommended.
5. Very Poor - Major changes necessary.

Please Circle The Appropriate Number

A. OVERFLOW LOGIC

1. How good was the overall logic of the display format?

						Mean Rating
CC	1	2	3	4	5	2.66
RCC	1	2	3	4	5	2.33
P	1	2	3	4	5	2.58
BC	1	2	3	4	5	3.26

Rate the importance of the above characteristic/feature relative to its effect on safe aircraft operations during failure or emergency conditions.

Mean Importance Rating: 1.62

1	2	3	4	5
Very Important	Somewhat Important	Neither Important Nor Unimportant	Somewhat Unimportant	Very Unimportant

2. How well would you be able to evaluate the aircraft status?

						Mean Rating
CC	1	2	3	4	5	2.26
RCC	1	2	3	4	5	1.86
P	1	2	3	4	5	2.41
BC	1	2	3	4	5	2.93

Rate the importance of the above characteristic/feature relative to its effect on safe aircraft operations during failure or emergency conditions.

Mean Importance Rating: 1.57

1	2	3	4	5
Very Important	Somewhat Important	Neither Important Nor Unimportant	Somewhat Unimportant	Very Unimportant

3. How good is each concept at helping to avoid confusion about alert priority level?

						Mean Rating
CC	1	2	3	4	5	2.66
RCC	1	2	3	4	5	2.33
P	1	2	3	4	5	2.53
BC	1	2	3	4	5	3.27

Rate the importance of the above characteristic/ feature relative to its effect on safe aircraft operations during failure or emergency conditions.

Mean Importance Rating: 1.50

1	2	3	4	5
Very Important	Somewhat Important	Neither Important Nor Unimportant	Somewhat Unimportant	Very Unimportant

4. How good is the probability of avoiding errors with the concept?

						Mean Rating
CC	1	2	3	4	5	2.67
RCC	1	2	3	4	5	2.20
P	1	2	3	4	5	2.76
BC	1	2	3	4	5	3.26

Rate the importance of the above characteristic/ feature relative to its effect on safe aircraft operations during failure or emergency conditions.

Mean Importance Rating: 1.50

1	2	3	4	5
Very Important	Somewhat Important	Neither Important Nor Unimportant	Somewhat Unimportant	Very Unimportant

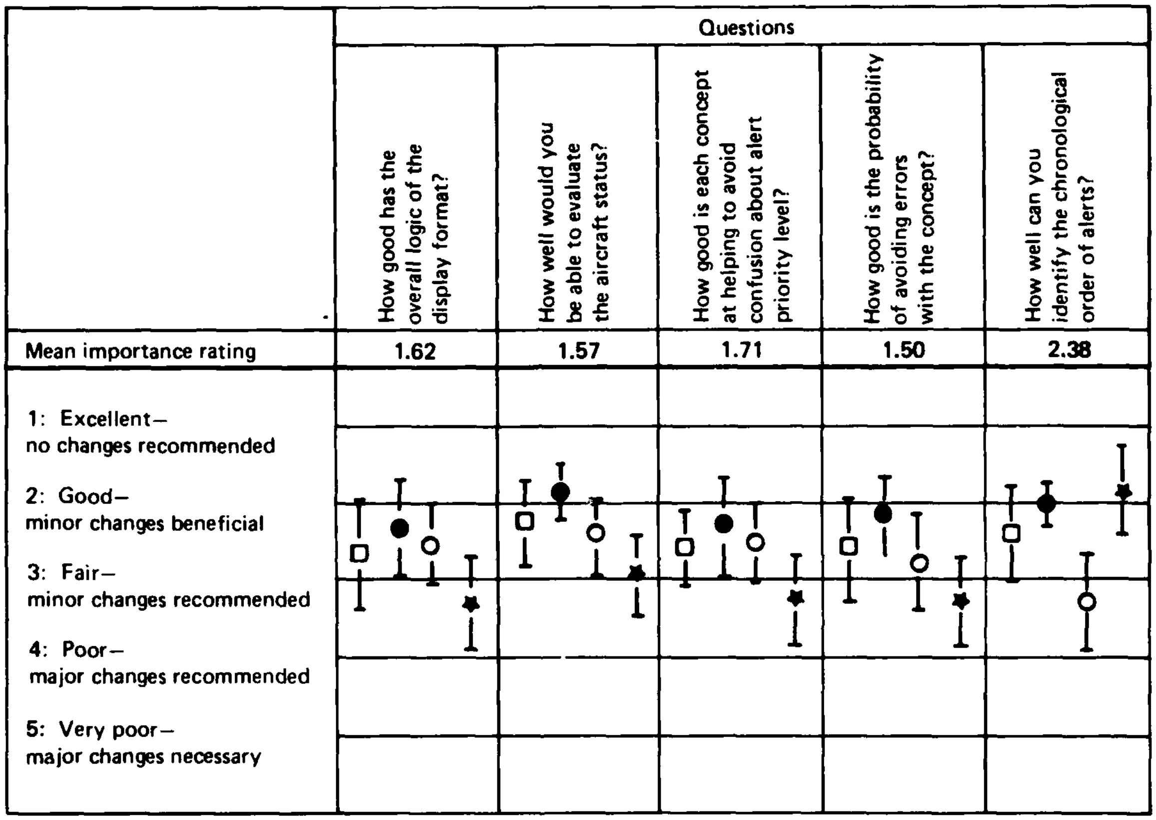
5. How well can you identify the chronological order of alerts?

						Mean Rating
CC	1	2	3	4	5	2.40
RCC	1	2	3	4	5	2.07
P	1	2	3	4	5	3.27
BC	1	2	3	4	5	1.86

Rate the importance of the above characteristic/ feature relative to its effect on safe aircraft operations during failure or emergency conditions.

Mean Importance Rating: 2.38

1	2	3	4	5
Very Important	Somewhat Important	Neither Important Nor Unimportant	Somewhat Unimportant	Very Unimportant



Importance rating scale:

1. Very important
2. Somewhat important
3. Neither important nor unimportant
4. Somewhat unimportant
5. Very unimportant

Display format:

- □ Chronology within color
- ● Reverse chronology within color
- ○ Priority
- ★ Basic chronology

Figure D-1. Mean Pilot Ratings for Overflow Logic Options (With 95% Confidence Limits)

Please Circle The Appropriate Number

Please answer the questions in Sections B, C and D using the five-point rating scale (Excellent to Very Poor) shown on Page 1.

B. BASIC DISPLAY CHARACTERISTICS

						Mean Rating
1. Character Spacing	1	2	3	4	5	1.71
2. Word Spacing	1	2	3	4	5	1.76
3. Line Spacing	1	2	3	4	5	2.00
4. Stroke Width	1	2	3	4	5	2.12
5. Contrast With Background						
a) Red Messages	1	2	3	4	5	1.64
b) Yellow Messages	1	2	3	4	5	1.70
c) Blue Messages	1	2	3	4	5	2.05
d) White Peripheral Information	1	2	3	4	5	2.11

C. PERIPHERAL INFORMATION

1. Rate the following characteristics of the mode indicator (Alert/Memory) on the display screen.

						Mean Rating
a) How well does it indicate system mode?	1	2	3	4	5	2.17
b) How effectively is it located on the screen?	1	2	3	4	5	2.17
c) How effective is the color (White) in helping to differentiate it from the alert messages?	1	2	3	4	5	2.35

d) Do you feel there is a better way of presenting this information? If so, please explain.

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2. New Message Indicator (Asterisk)

							Mean Rating
a)	How well does it aid in detecting the most recent alert for the first time?	1	2	3	4	5	2.76
b)	How effective is the flash rate in drawing your attention to a new message?	1	2	3	4	5	2.35

3. New Message Indicator (Colored Box Around Message)

a)	How well does it aid in detecting the most recent alert for the first time?	1	2	3	4	5	1.41
b)	How effective is the flash rate in drawing your attention to a new message?	1	2	3	4	5	1.35
c)	How effective would it be if used to replace the master lights in the pilots primary field of view?	1	2	3	4	5	3.00

d) Do you feel that there is a better way to present this information? If so please explain.

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4. Page Number Indicator

							Mean Rating
a)	Size	1	2	3	4	5	2.41
b)	Location	1	2	3	4	5	2.59
c)	Contrast With Alert Messages	1	2	3	4	5	2.47
d)	Clarity Of Meaning	1	2	3	4	5	2.88

e) Do you feel there is a better way of presenting this information?

5. Cursor (Line Advance Indicator)

							Mean Rating
a)	Size	1	2	3	4	5	1.94
b)	Shape	1	2	3	4	5	2.06
c)	Dynamics Relative to Key Input	1	2	3	4	5	2.13
d)	Contrast With Alert Messages	1	2	3	4	5	2.00

e) Do you feel there is a better way of presenting this information?

6. Colored Boxes Used To Indicate The Presence Of An Overflow Condition (Additional Messages On Page 2 And/Or 3).

							Mean Rating
a)	Size	1	2	3	4	5	2.06
b)	Shape	1	2	3	4	5	1.94
c)	Location	1	2	3	4	5	2.00
d)	Ease Of Differentiation Between Warning, Caution And Advisory Message Indicators	1	2	3	4	5	2.00

e) Effectiveness Of Flash Rate Used To Indicate The Presence Of New Message On Page 2 Or 3	1	2	3	4	5	1.88
f) Color Contrast Between Colored Boxes And Messages Within Them	1	2	3	4	5	2.00
g) Ability To Avoid Confusion Regarding The Number Of Messages For Each Alert Level Being Stored On Pages 2 And 3	1	2	3	4	5	2.70

h) Do you feel there is a better way of presenting this information?

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7. Deferred Item Indicator (Memory Symbol)

						Mean Rating
a) Size	1	2	3	4	5	2.28
b) Shape	1	2	3	4	5	2.14
c) Location	1	2	3	4	5	2.14
d) Ability To Differentiate Between Messages Being Stored In Memory And Those Being Stored On Pages 2 And 3	1	2	3	4	5	2.50
e) Ability To Avoid Confusion Regarding Number Of Messages Being Stored In Memory	1	2	3	4	5	2.57
f) Clarity Of Meaning	1	2	3	4	5	2.07

g) Do you feel there is a better way of presenting this information?

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8. Function Keys (Located To The Left Of The Display Screen)						Mean Rating
a) Size	1	2	3	4	5	1.87
b) Shape	1	2	3	4	5	1.80
c) Location						
1 - Mode Key	1	2	3	4	5	2.00
2 - Checklist Key	1	2	3	4	5	1.93
3 - Line Advance Key	1	2	3	4	5	1.86
4 - Store Key	1	2	3	4	5	1.86
5 - Page Key	1	2	3	4	5	1.79
d) Contrast Between Legends And Backgrounds	1	2	3	4	5	2.07
e) How Well Do The Display Dynamics Correspond To Key Inputs?	1	2	3	4	5	2.14

9. Line Keys (Located To The Right Of The Display Screen)						Mean Rating
a) Size	1	2	3	4	5	2.54
b) Shape	1	2	3	4	5	2.53
c) Location	1	2	3	4	5	2.53
d) Contrast Between Legends And Backgrounds	1	2	3	4	5	2.46
e) How Well Do Display Dynamics Correspond To Key Inputs?	1	2	3	4	5	2.58

f) Do you feel there is a better way of presenting this information?

D. USE OF COLOR TO DIFFERENTIATE BETWEEN WARNING, CAUTION AND ADVISORY MESSAGES

						Mean Rating
1. How Well Can You Distinguish Between Alert Priority Level?	1	2	3	4	5	1.31
2. How Effective Is Color As An Aid In The Evaluation Of Aircraft Status?	1	2	3	4	5	1.18
3. How Well Does Color Help Avoid The Possibility of Confusing Alert Priority Level?	1	2	3	4	5	1.25

4. If You Were To Suggest A More Effective Color Coding Scheme As An Alternative To Red, Yellow, And Blue, What Colors Would You Recommend?

APPENDIX E

FAA
ALERTING SYSTEM STANDARDIZATION STUDY
PRIORITIZATION AND INHIBIT QUESTIONNAIRE
RESULTS

ORGANIZATION REPRESENTED

Organization	Number of Pilots
Douglas Aircraft Company	7
Boeing Commercial Airplane Company	2
Lockheed California Company	3
Continental Airlines	4
Western Airlines	5
Total Number of Pilots Responding	21

AIRCRAFT TYPES REPRESENTED (VEHICLE OF MOST RECENT EXPERIENCE)

Aircraft Type	Number of Pilots
DC-9	3
DC-10	5
B727	9
B747	1
L-1011	3

MEAN NUMBER OF FLIGHT HOURS: 11,669

AD-A107 225 BOEING COMMERCIAL AIRPLANE CO SEATTLE WA F/G 1/2
AIRCRAFT ALERTING SYSTEMS STANDARDIZATION STUDY. VOLUME I. CAND--ETC(U)
JAN 81 G P BOUCEK, D A PO-CHEDLEY, B L BERSON DOT-FA/9WA-4268
UNCLASSIFIED FAA/RD-81/38/1 NL

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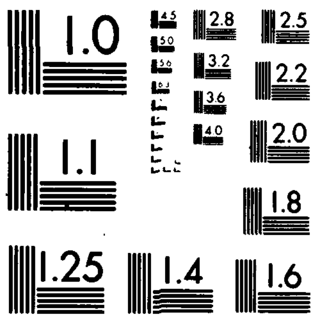

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Means and 95% confidence limits for the 16 alerts used in the prioritization questionnaire:

1. Anti Skid Left Inboard Failure
2. APU Fire
3. Left Fuel Pump Valve Open
4. Battery Bus Off
5. Generator Off
6. Galley Overheat
7. APU Generator Off
8. Cabin Pressure Relief Valve Open
9. Wing Anti Ice Disagree
10. Air Condition Pack
11. Duct Avionic Compartment Overheat
12. Engine Fire
13. Left Emergency AC Bus Off
14. GPWS
15. Manifold Failure (Pneumatic)
16. Cabin Altitude

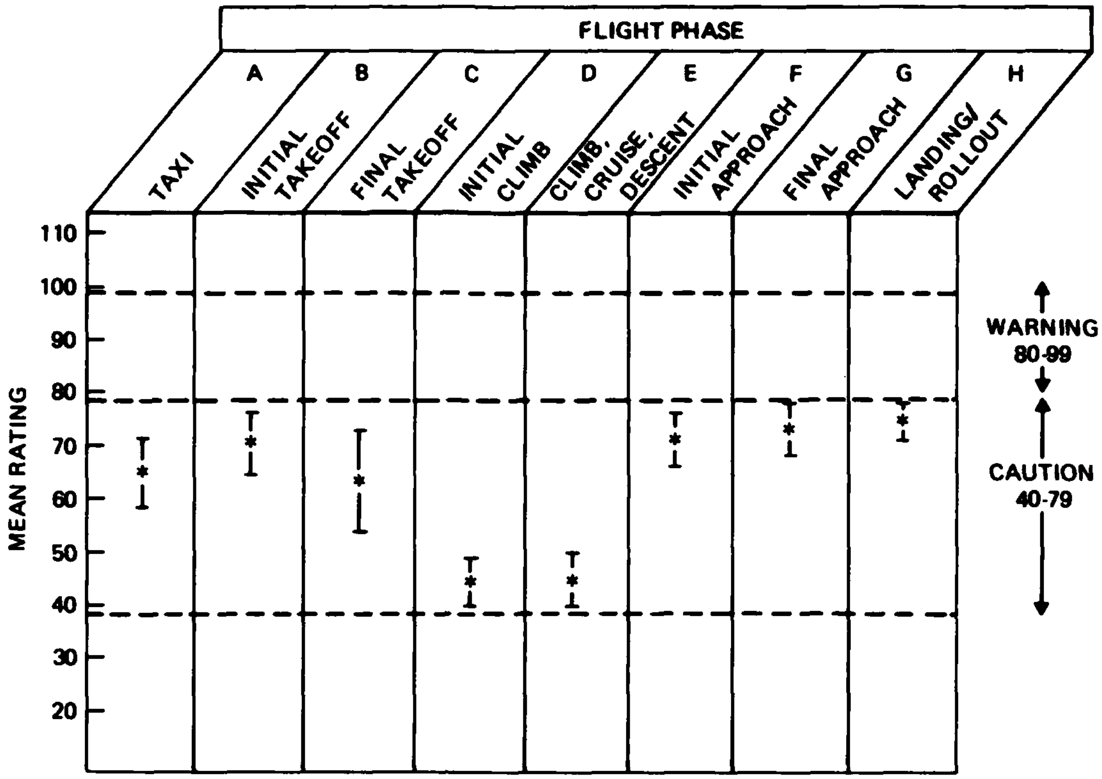

Figure E-1. Means and Confidence Limits for Pilot Ratings of Selected Alerts—Antiskid L Inbd Fail

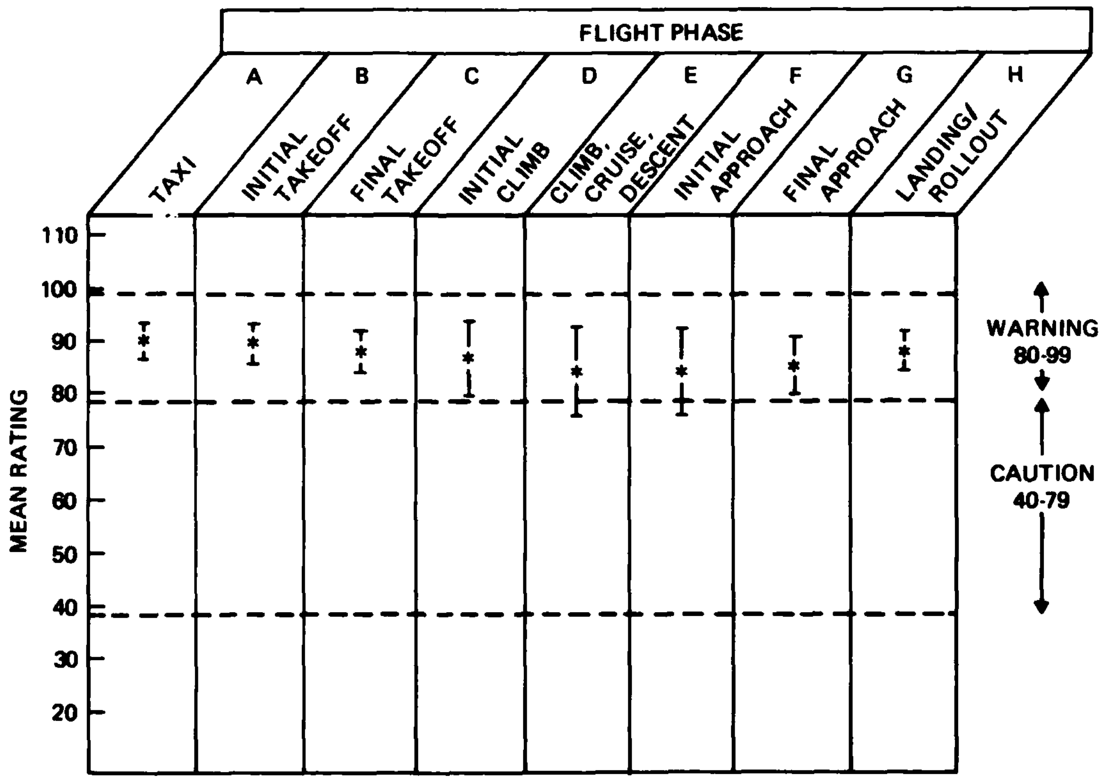

Figure E-2. Means and Confidence Limits for Pilot Ratings of Selected Alerts—APU Fire

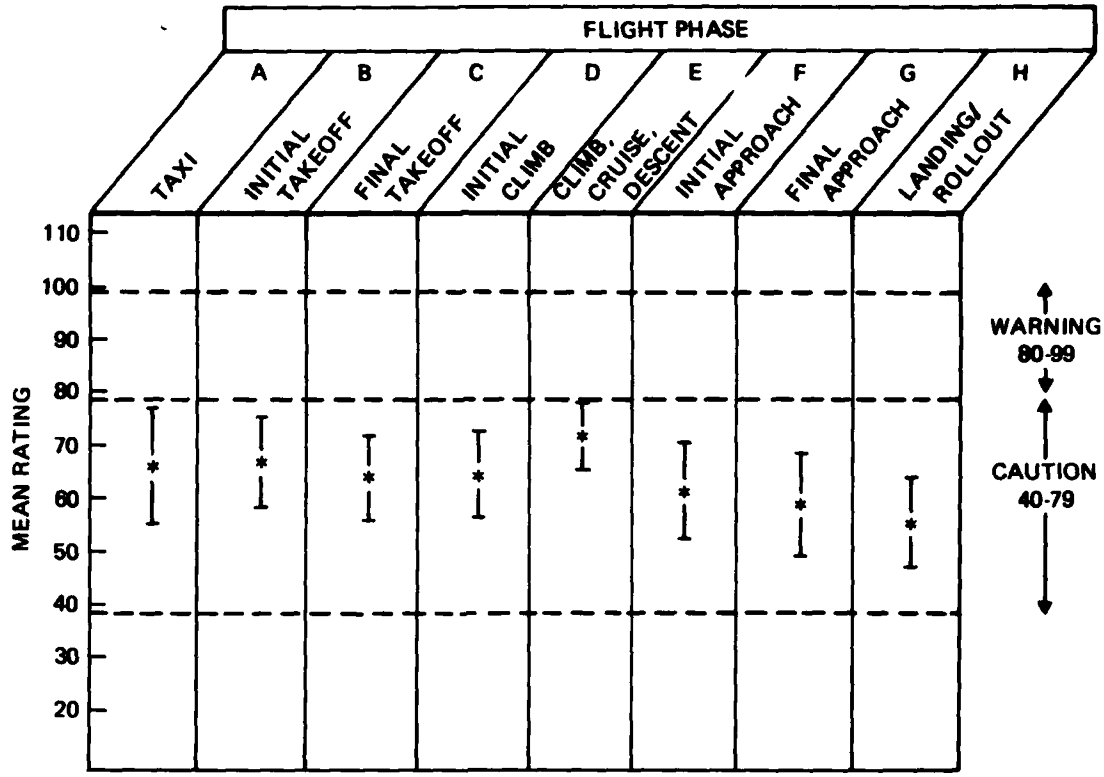

Figure E-3. Means and Confidence Limits for Pilot Ratings of Selected Alerts—L Fuel Dump Valve Open

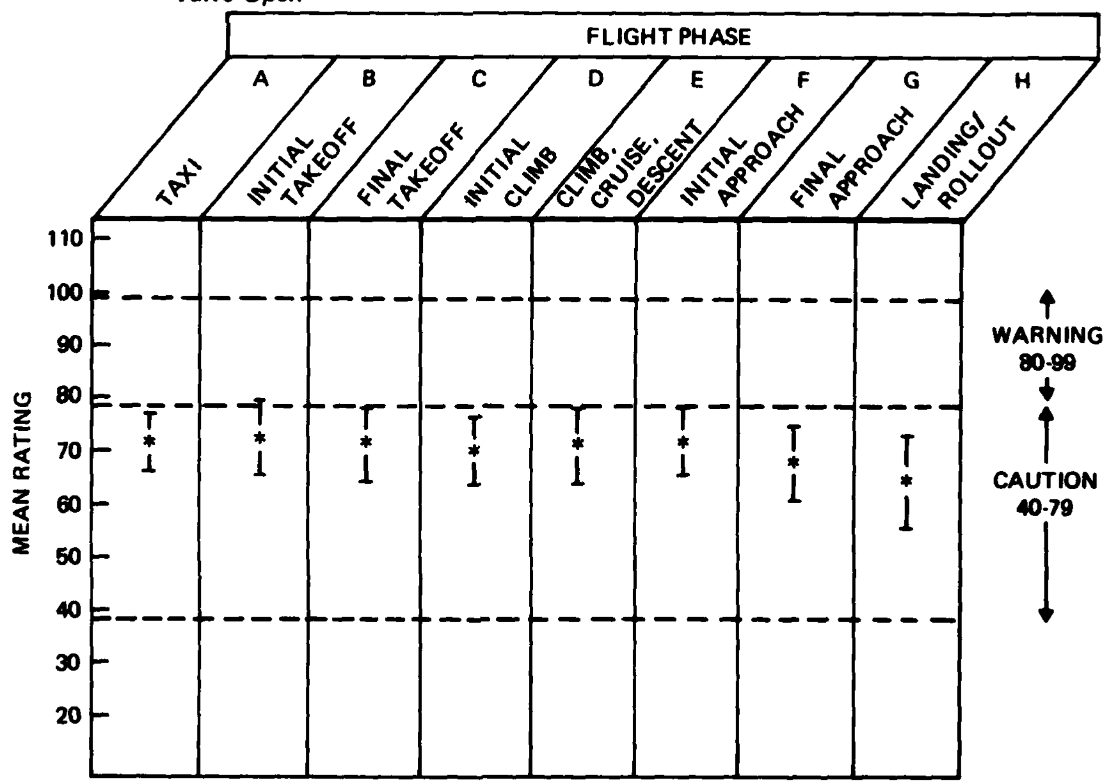

Figure E-4. Means and Confidence Limits for Pilot Ratings of Selected Alerts—Battery Bus Off

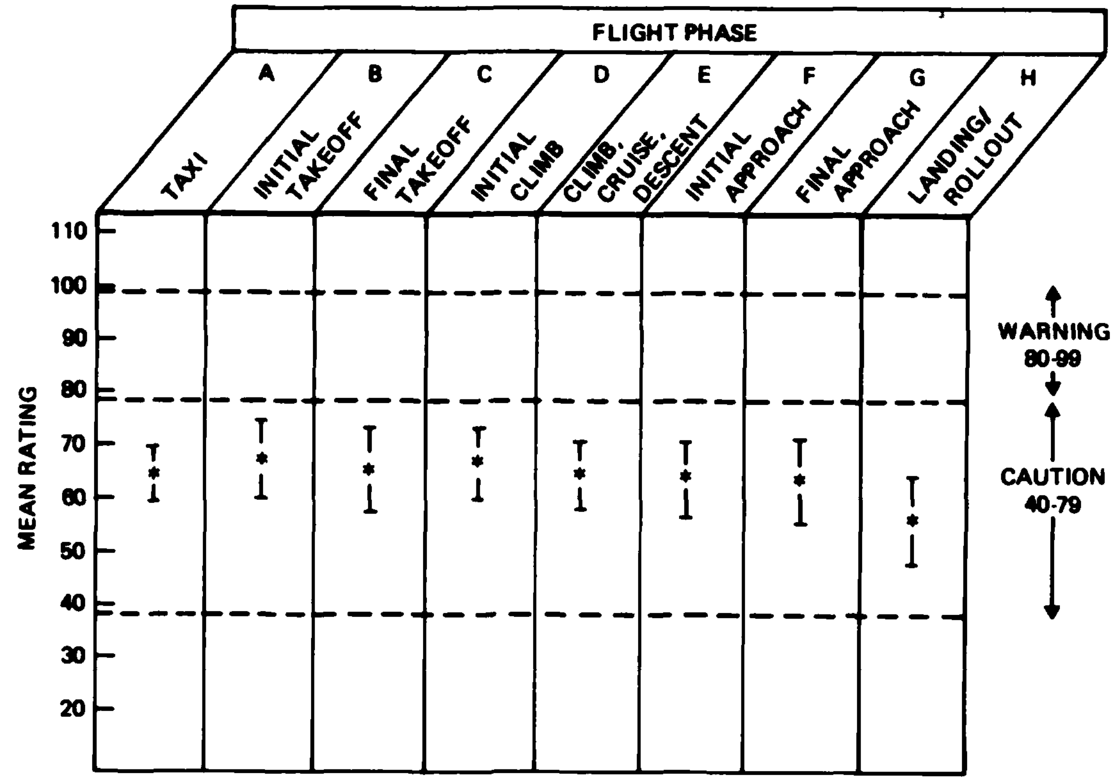

Figure E-5. Means and Confidence Limits for Pilot Ratings of Selected Alerts—Gen Off

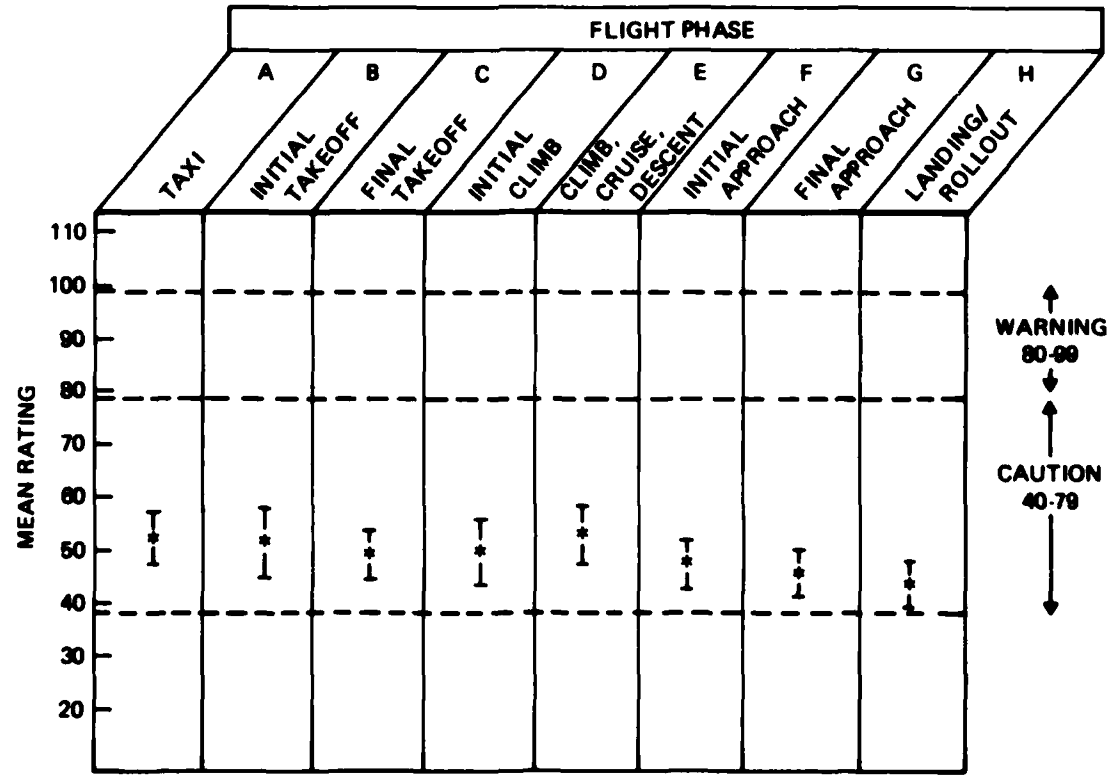

Figure E-6. Means and Confidence Limits for Pilot Ratings of Selected Alerts—Gallery Overheat

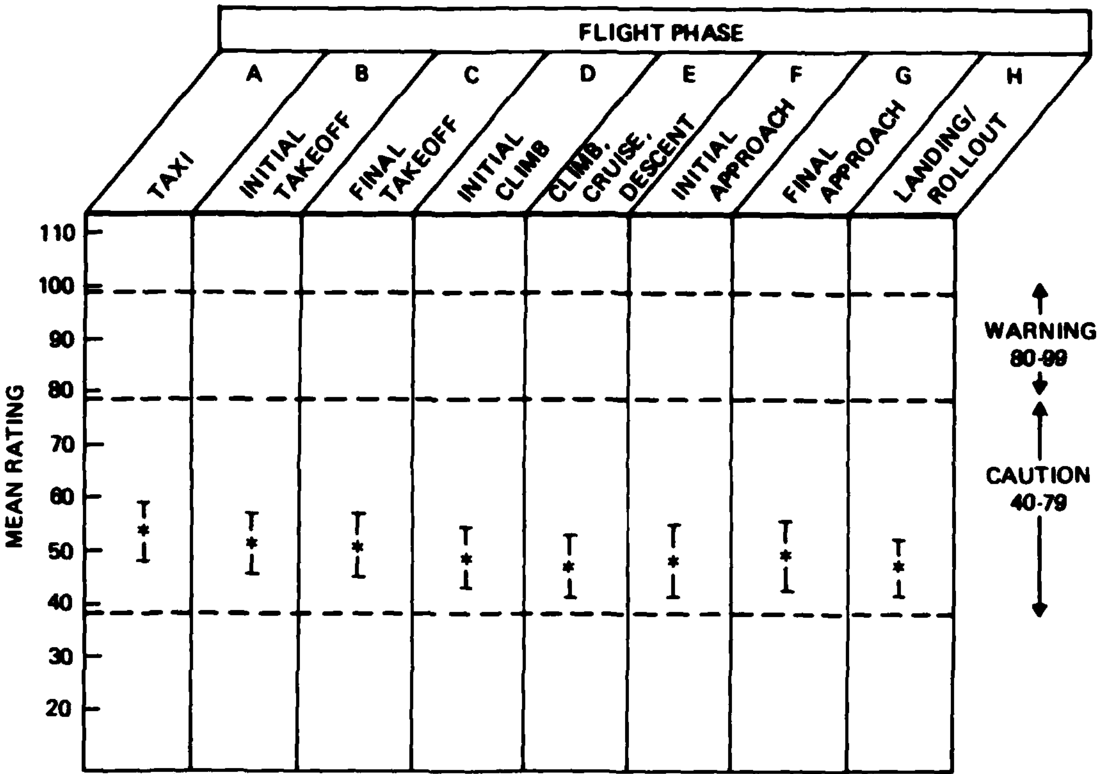

Figure E-7. Means and Confidence Limits for Pilot Ratings of Selected Alerts—APU Gen Off

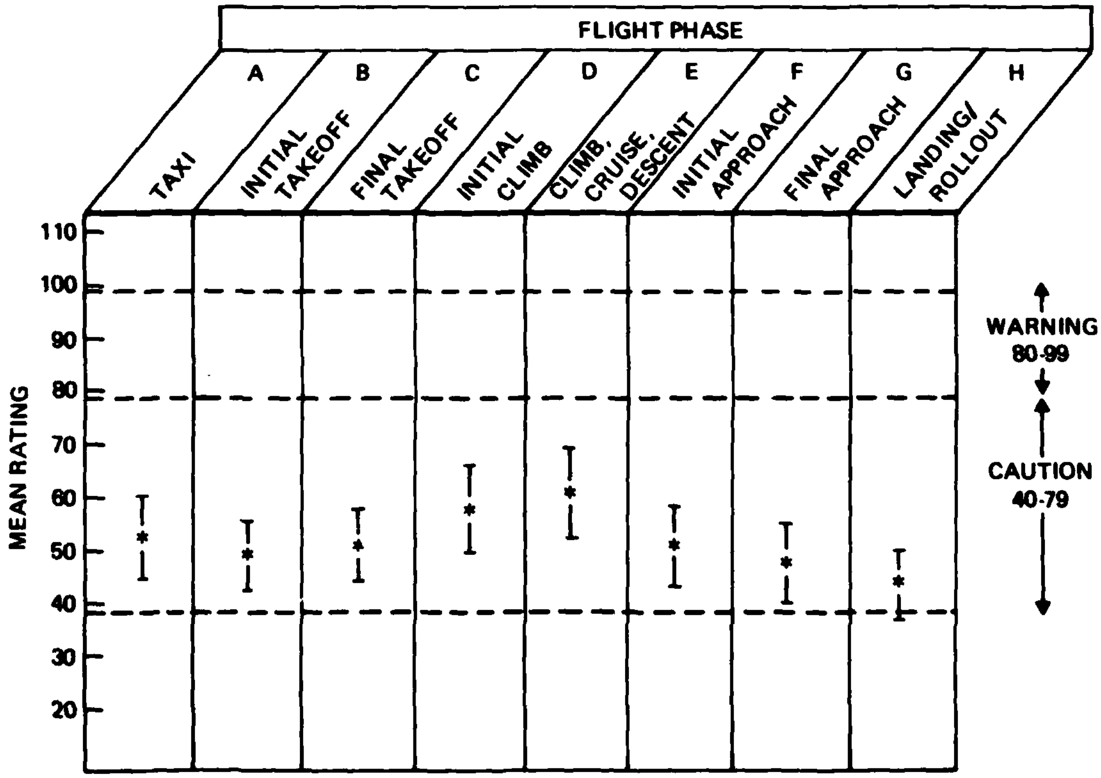

Figure E-8. Means and Confidence Limits for Pilot Ratings of Selected Alerts—Cabin Press Relief Valve Open

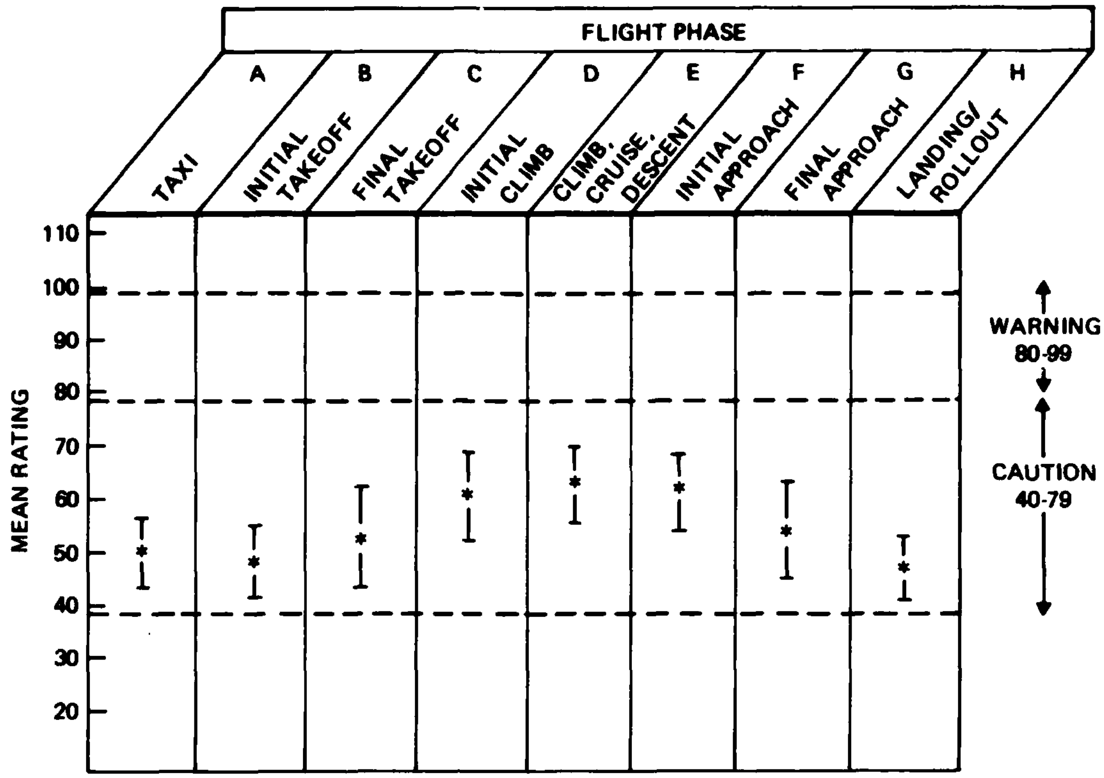

Figure E-9. Means and Confidence Limits for Pilot Ratings of Selected Alerts—Wing Anti-ice Disagree

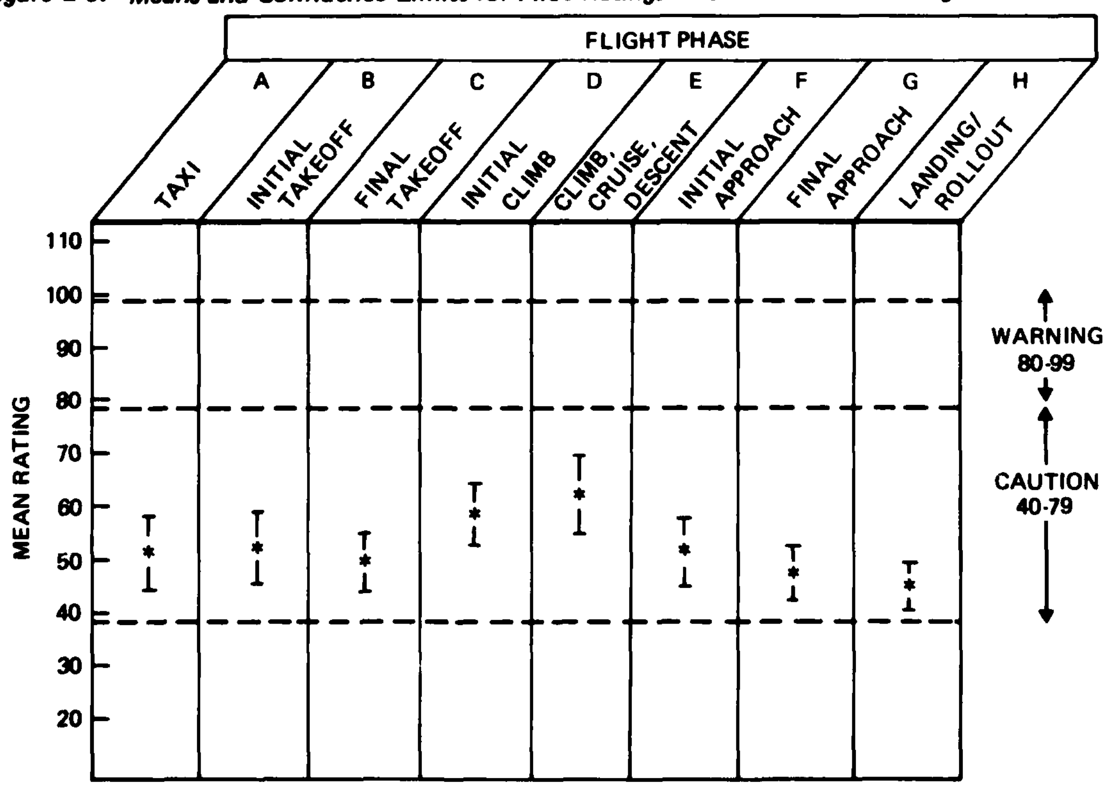

Figure E-10. Means and Confidence Limits for Pilot Ratings of Selected Alerts—Air Cond Pack Off

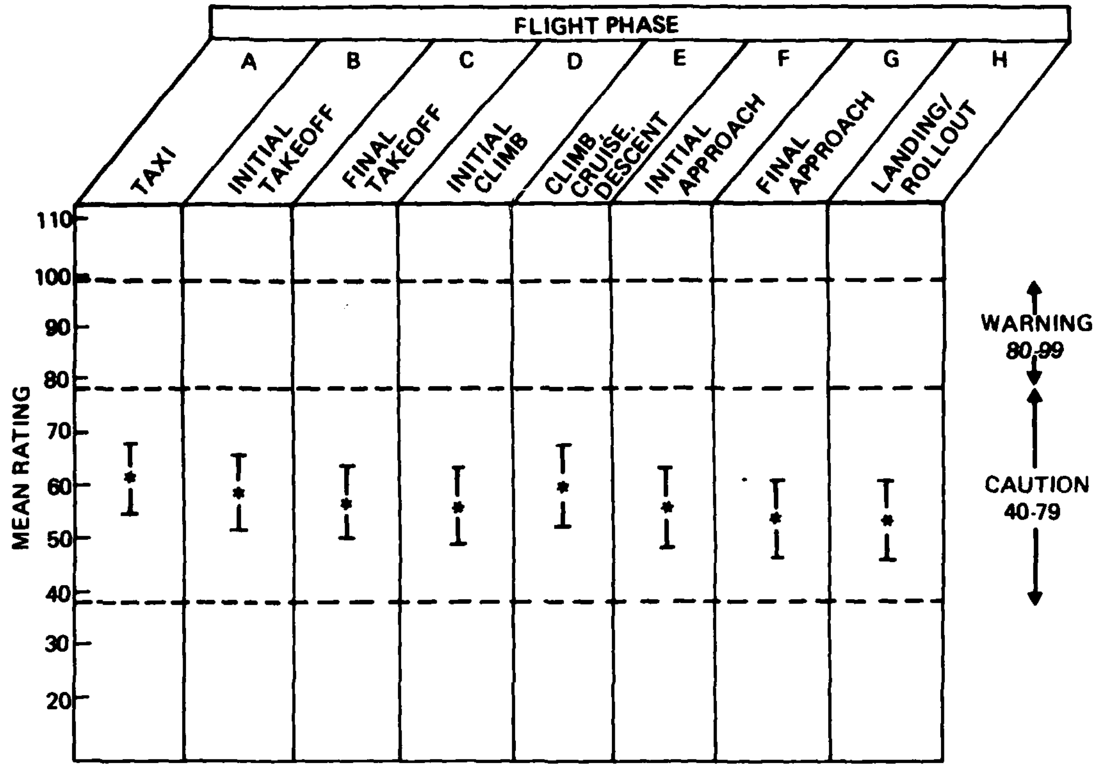

Figure E-11. Means and Confidence Limits for Pilot Ratings of Selected Alerts—Duct Avionic Comp Overheat

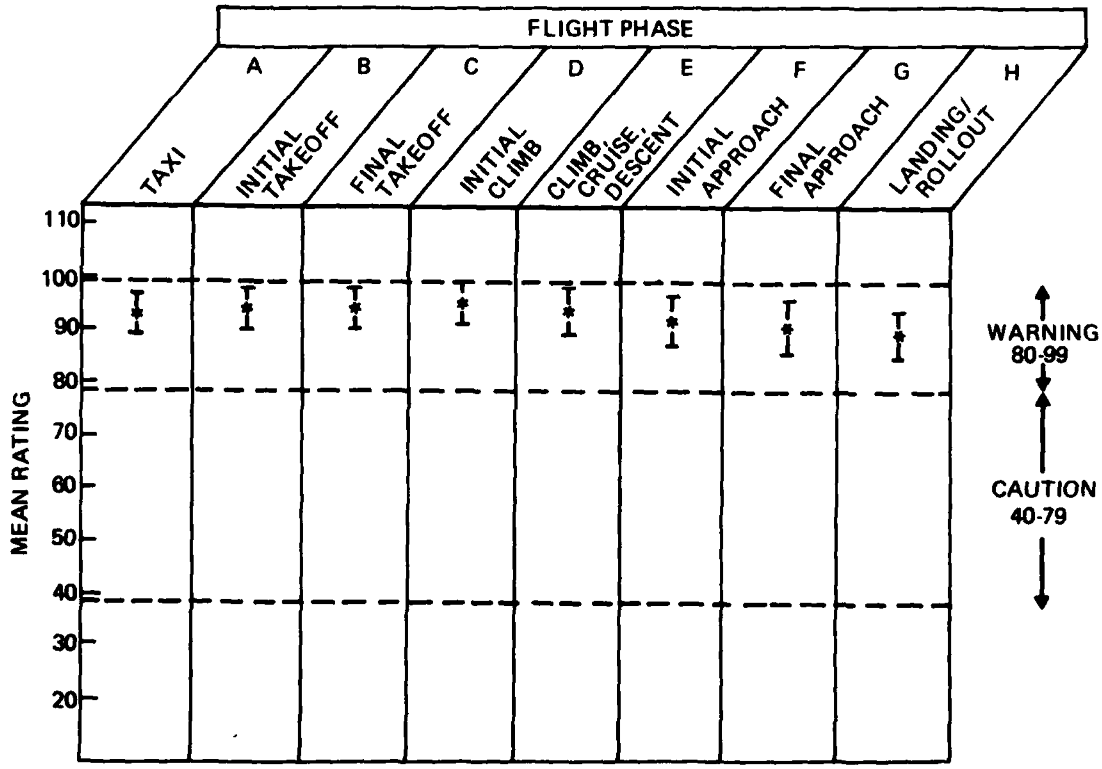

Figure E-12. Means and Confidence Limits for Pilot Ratings of Selected Alerts—Eng Fire

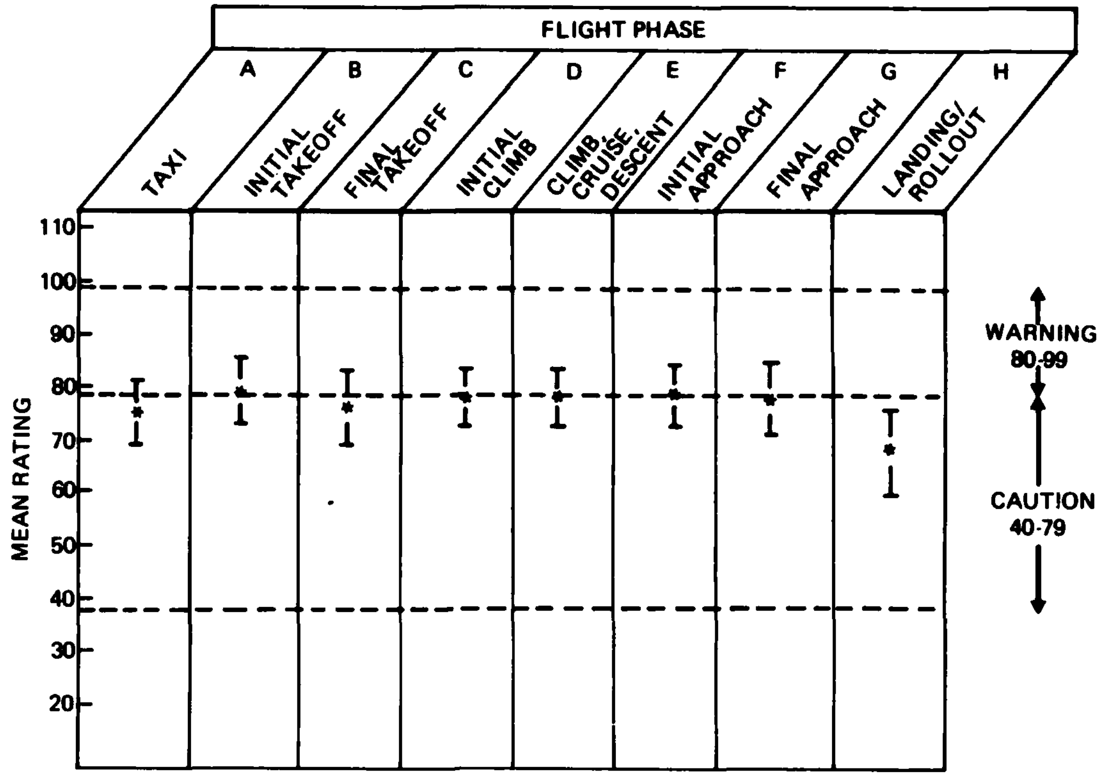

Figure E-13. Means and Confidence Limits for Pilot Ratings of Selected Alerts—L Emer AC Bus Off

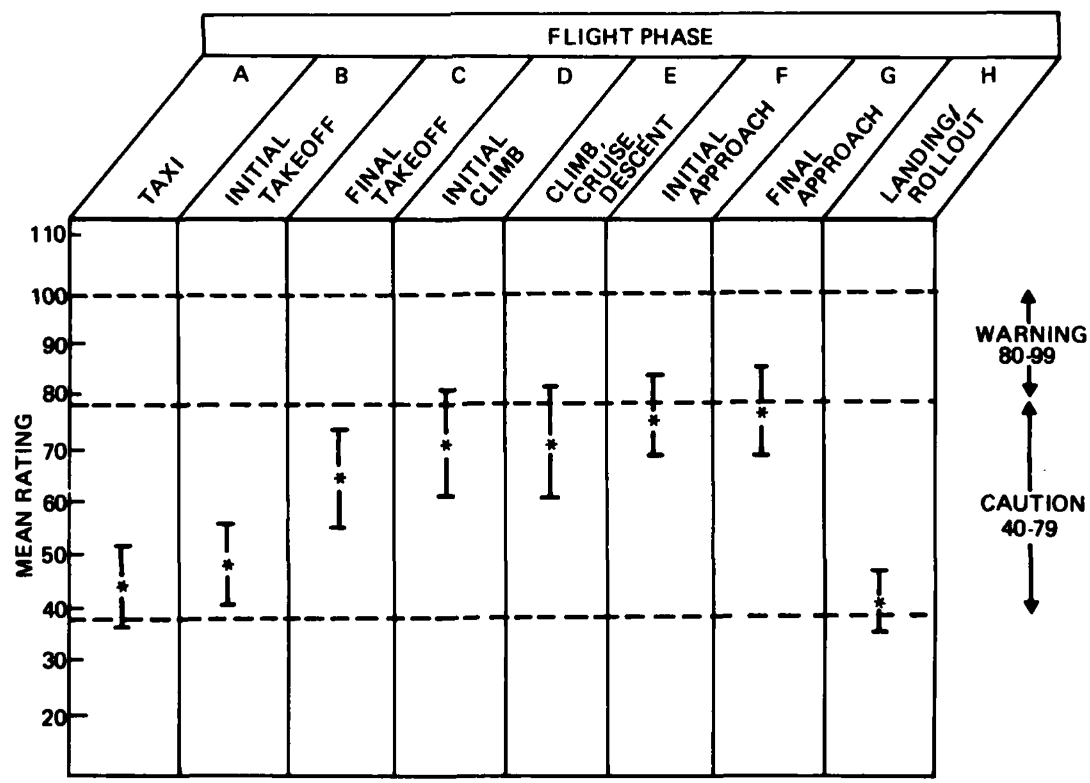

Figure E-14. Means and Confidence Limits for Pilot Ratings of Selected Alerts—GPWS

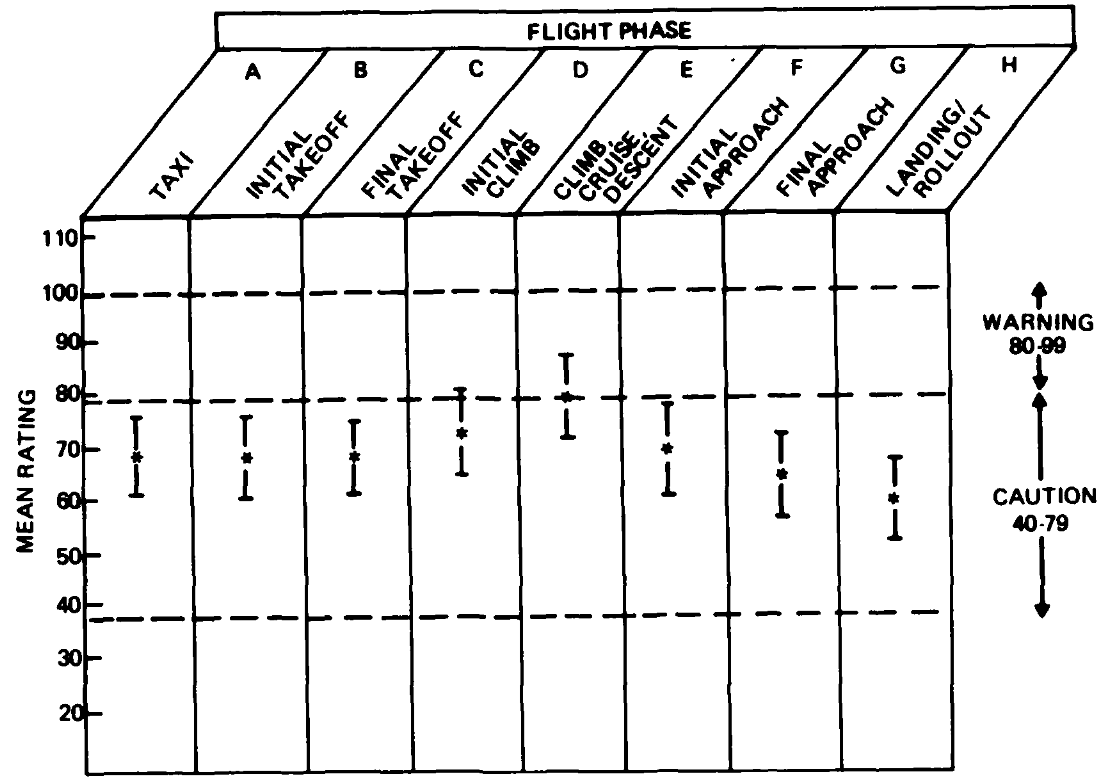

Figure E-15. Means and Confidence Limits for Pilot Ratings of Selected Alerts—Manifold Fail (Pneu)

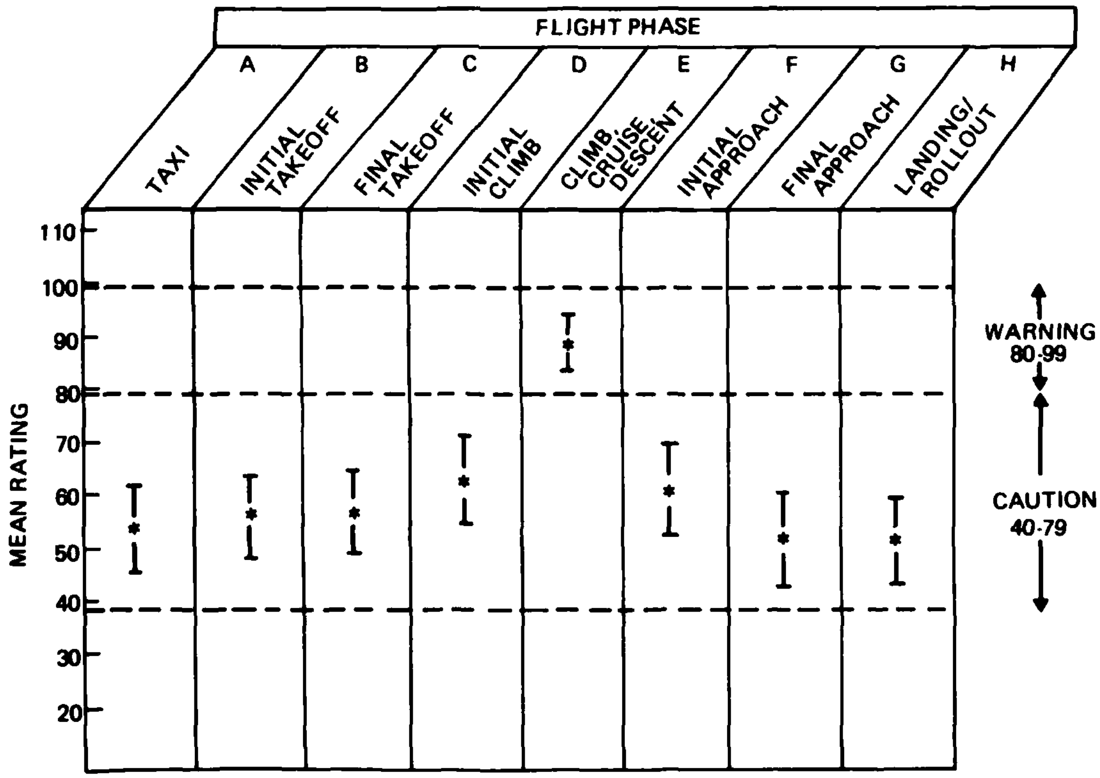

Figure E-16. Means and Confidence Limits for Pilot Ratings of Selected Alerts—Cabin Alt

Means and 95% confidence limits for the eight flight phases used in the prioritization questionnaire:

	Flight Phase	Definition
1.	Taxi	
2.	Initial Take Off	0 kts - 30 kts to 400 feet
3.	Final Take Off	V_1 - 30 kts to 400 feet
4.	Initial Climb	
5.	Climb/Cruise/Descent	
6.	Initial Approach	1,500 feet to 200 feet
7.	Final Approach	200 feet to Touchdown
8.	Landing Rollout	Touchdown to Taxi

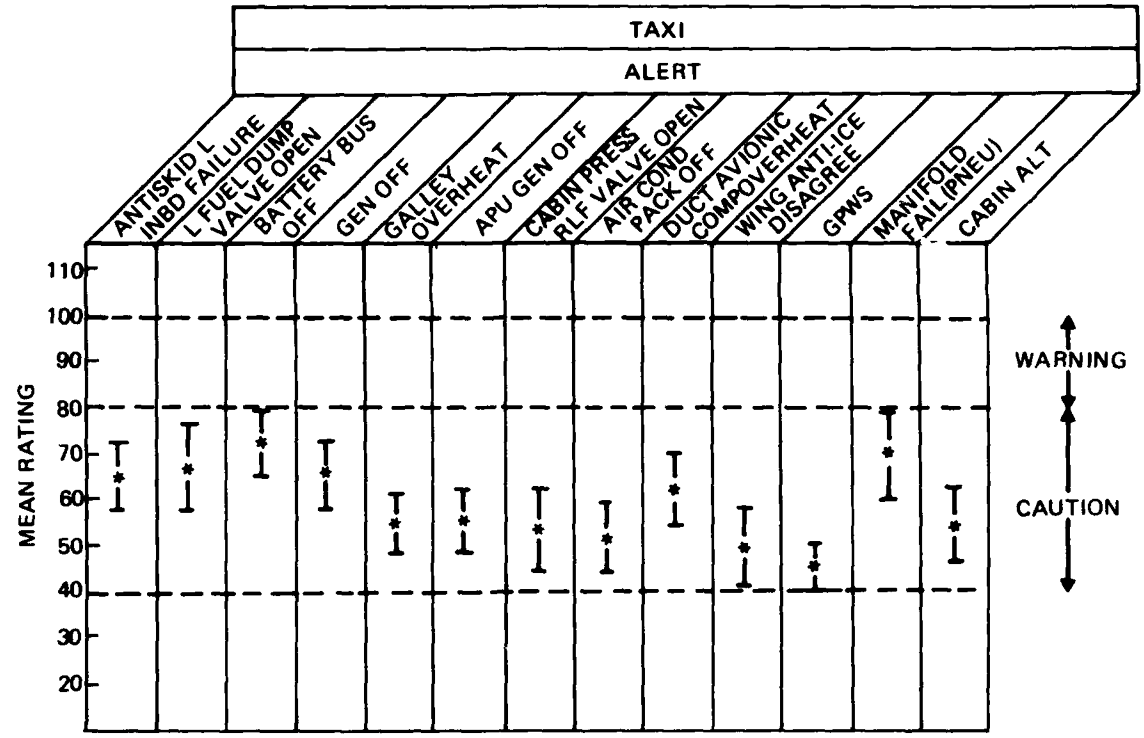

Figure E-17. Means and 95% Confidence Limits for Pilot Ratings of Selected Caution-Level Alerts--Taxi

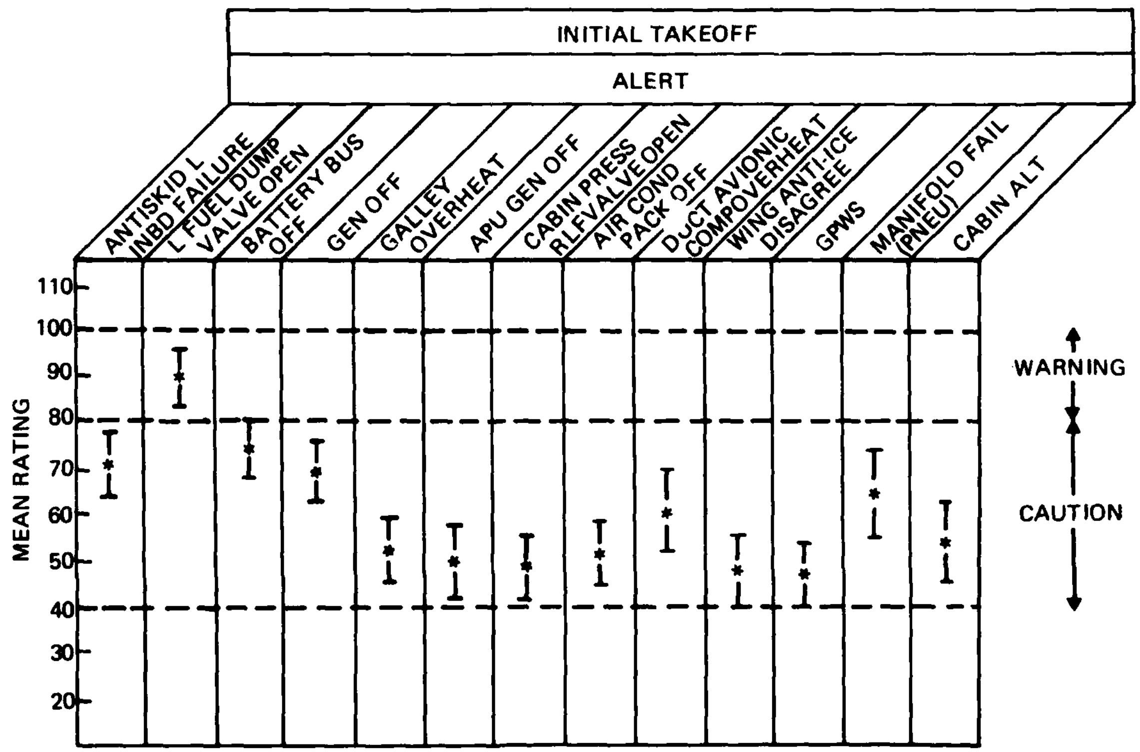

Figure E-18. Means and 95% Confidence Limits for Pilot Ratings of Selected Caution-Level Alerts—Initial Takeoff

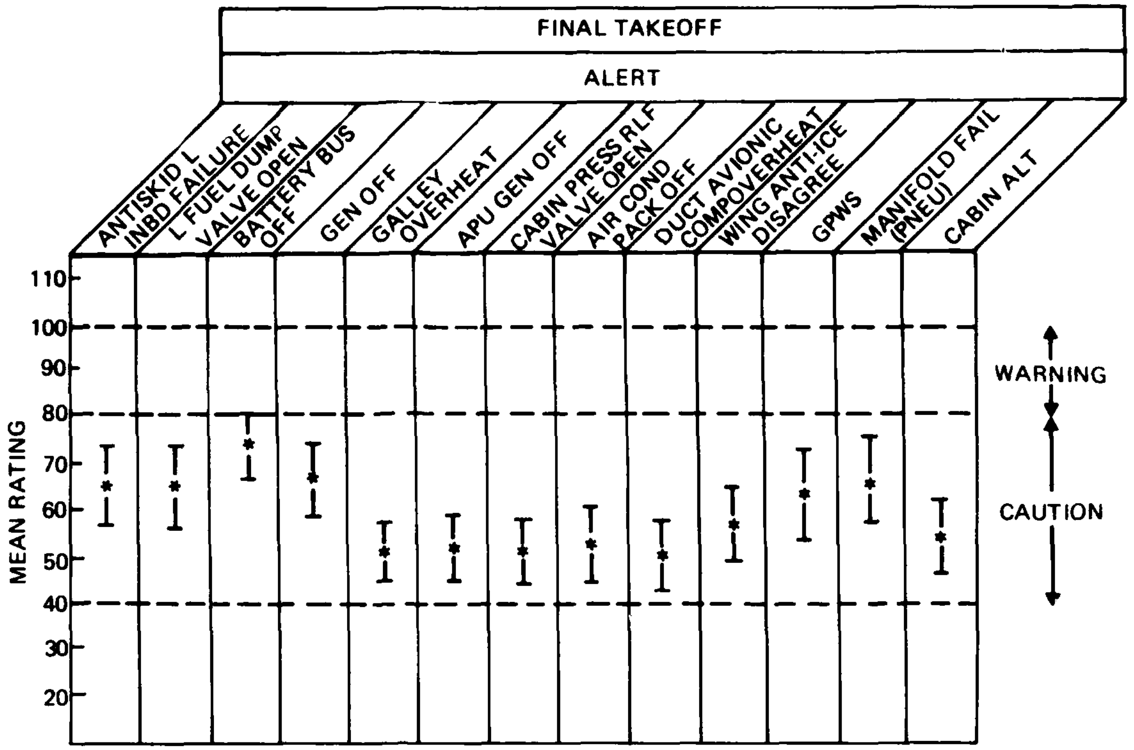

Figure E-19. Means and 95% Confidence Limits for Pilot Ratings of Selected Caution-Level Alerts—Final Takeoff

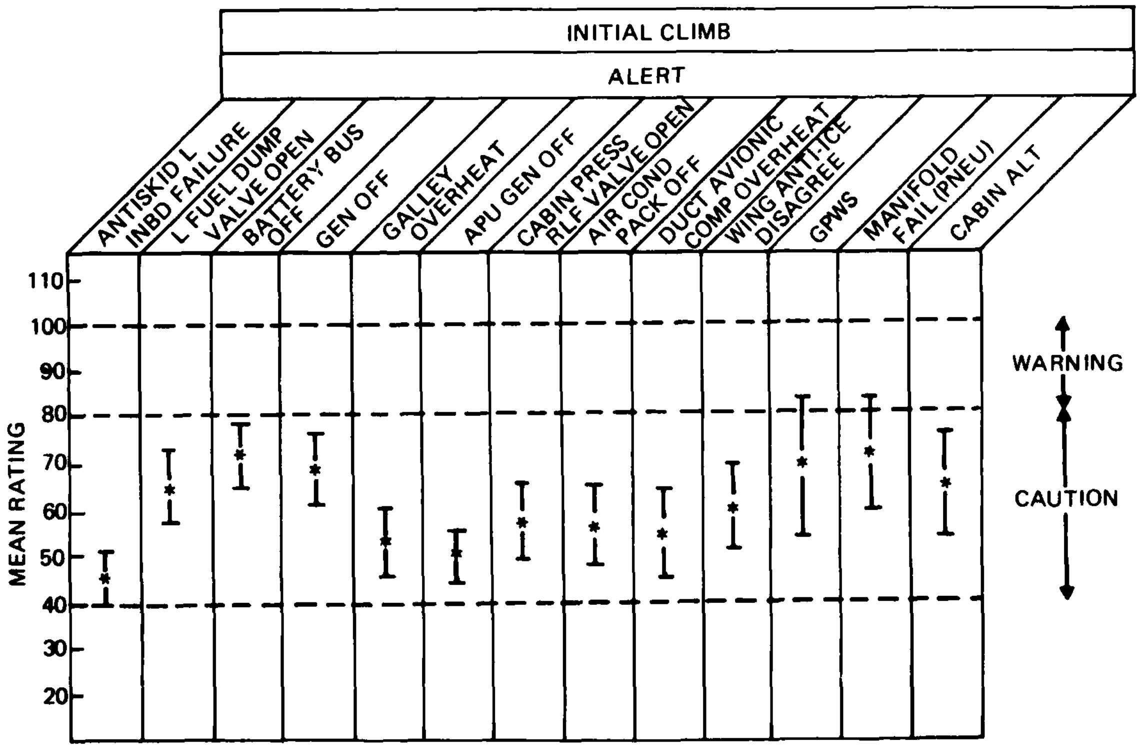

Figure E-20. Means and 95% Confidence Limits for Pilot Ratings of Selected Caution-Level Alerts—Initial Climb

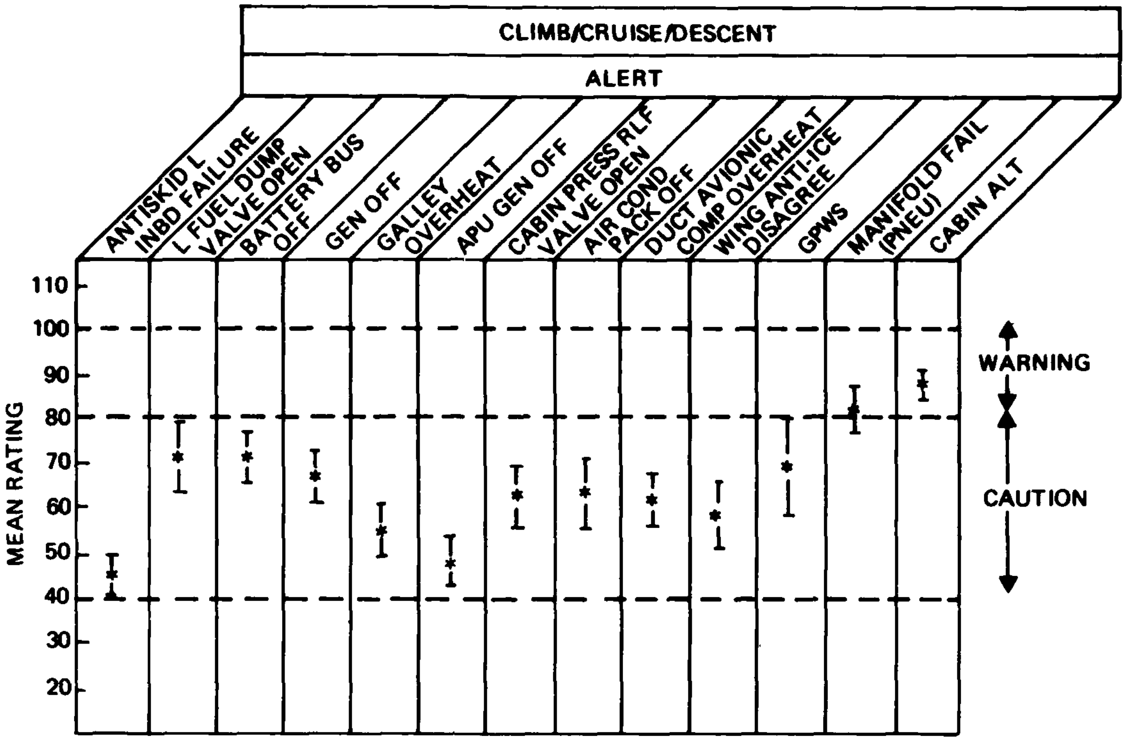

Figure E-21. *Means and 95% Confidence Limits for Pilot Ratings of Selected Caution-Level Alerts—Climb/Cruise/Descent*

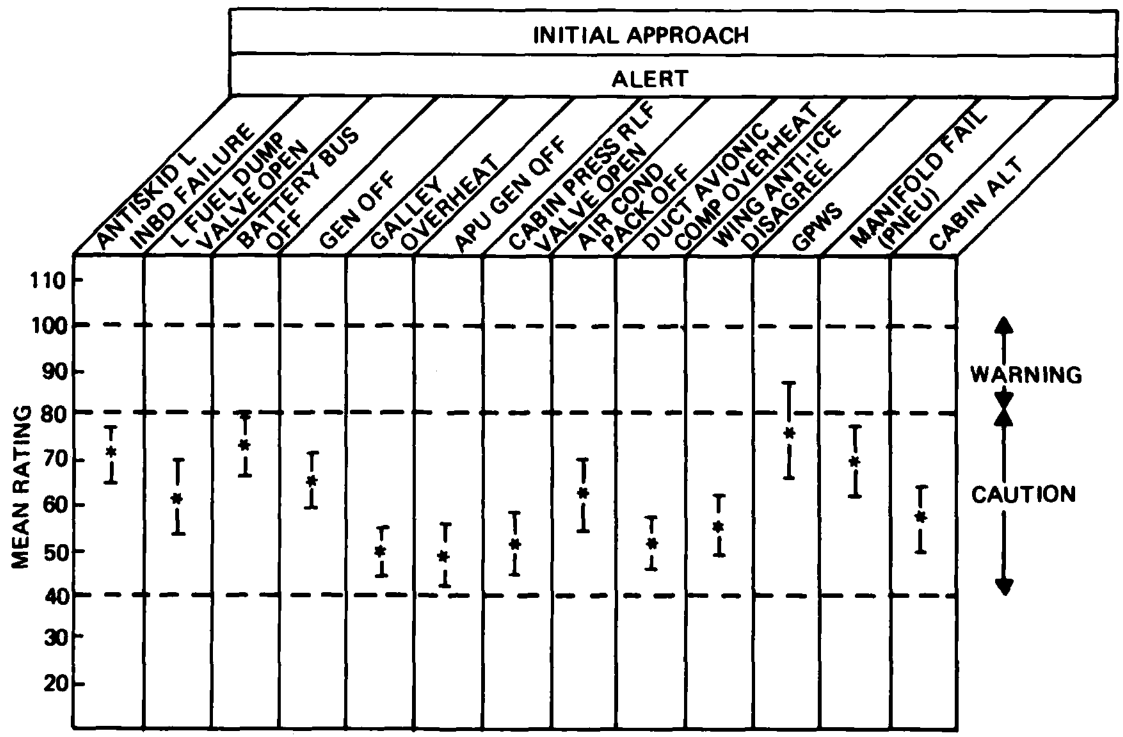

Figure E-22. *Means and 95% Confidence Limits for Pilot Ratings of Selected Caution-Level Alerts—Initial Approach*

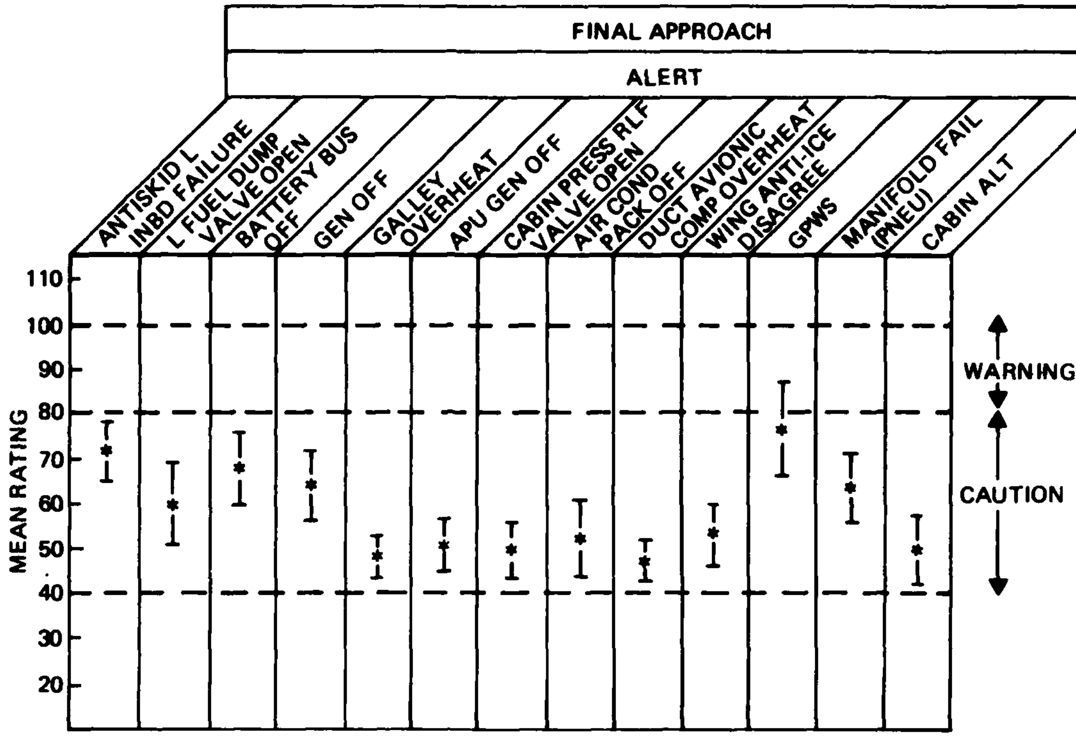

Figure E-23. Means and 95% Confidence Limits for Pilot Ratings of Selected Caution-Level Alerts—Final Approach

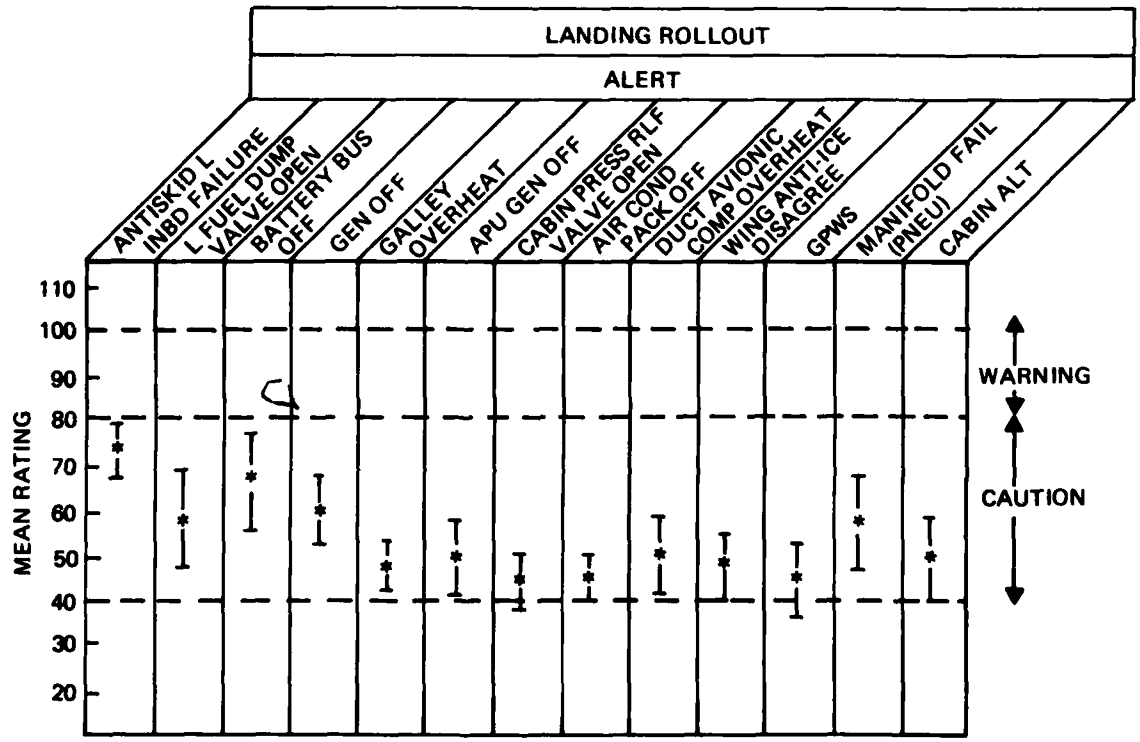

Figure E-24. Means and 95% Confidence Limits for Pilot Ratings of Selected Caution-Level Alerts—Landing Rollout

ALERTS	A TAXI	B INITIAL TAKEOFF	C FINAL TAKEOFF	D INITIAL CLIMB	E CLIMB, CRUISE, DESCENT	F INITIAL APPROACH	G FINAL APPROACH	H LANDING/ ROLLOUT	CONFIGURATION EXCEPTIONS
1. ANTISKID L INBD FAIL	19	19	47	47	42	20	28	28	28
2. APU FIRE	10	25	50	25	25	30	35	28	33
3. L FUEL DUMP VALVE OPEN	24	29	52	43	33	33	25	35	19
4. BATTERY BUS OFF	15	25	40	40	20	30	35	25	25
5. GEN OFF	10	15	35	25	10	20	40	30	50
6. GALLEY OVERHEAT	19	42	57	52	23	33	42	33	5
7. APU GEN OFF	25	40	60	50	35	40	55	35	20
8. CABIN PRESS RELIEF VALVE OPEN	28	47	57	47	24	33	57	45	10
9. WING ANTI-ICE DISAGREE	38	47	57	43	28	38	48	48	19
10. AIR COND PACK OFF	24	43	57	57	29	43	52	43	57
11. DUCT AVIONIC COMP OVERHEAT	15	35	60	50	25	35	45	30	5
12. ENG FIRE	14	19	47	38	14	29	52	33	33
13. L EMER AC BUS OFF	25	35	40	35	20	30	30	30	15
14. GPWS	32	42	47	42	37	32	47	52	10
15. MANIFOLD FAIL (PNEU)	23	33	57	42	23	33	47	38	10
16. CABIN ALT	45	55	66	52	14	47	71	60	10

*Percentage of pilots who favored alert inhibition during each flight phase, and percentage who foresaw the need for configuration exceptions for each alert.

*Figure E-25. Alert Inhibit Logic Summary**

APPENDIX F

PILOT TRAINING CHECKLIST

Pilot Briefing Checklist

I. INTRODUCTION

1. Background
   a. This is an FAA program that develops a systematic approach to crew alerting.
   b. The program is a three-phase effort; phases 1 and 2 are completed.
   c. The first phase evaluated elements of the alerting system and developed candidate system concepts.
   d. The second phase provided the design of tests that evaluated candidate systems.

   You will participate in these tests.

2. Phase 3 objectives
   a. Resolve problems and include results in test
   b. Validate the advanced pilots design
   c. Validate the advanced flight engineer design
   d. Evaluate time-critical presentation media
   e. Provide guidelines for designers of alerting systems

II. FLIGHT TASK

1. Active displays
   a. EADI
   b. HSI/DME
   c. Airspeed
   d. Altimeter
   e. Vertical speed
   f. Clock
   g. Alert display(s)
   h. Engine instrument
   i. Flaps
   j. 12 key
2. Active controls
   a. Wheel and column
   b. Rudder and toe brake
   c. Speed brake
   d. Flaps
   e. Gear
   f. Fire handle
   g. Response switches
   h. 12 key
   i. Throttles

Pilot Briefing Checklist (Concluded)

II. FLIGHT TASK (Continued)

3. Flightpath
    a. Takeoff
    b. Climb
    c. Cruise
    d. Descent—cloud layer
    e. Land
    f. Turns
    g. Autothrottle
    h. Windshear
    i. Updates
4. ATC
    a. Flightpath direction
    b. Traffic annunciation

III. CREW ALERTING

1. Advanced system displays
    a. Information
    b. Master visual
    c. Master aural
    d. Voice alerts
    e. Time critical
    f. EADI change
2. Conventional system display
    a. Distributed alerts
    b. Annunciator panel
    c. Discrete tones
3. Alert response
    a. Flight management responses
    b. System management responses
4. Review alerts and responses

IV. TRAINING FLIGHTS

1. Airplane familiarization flight
    a. Review handling
    b. Introduce ATC guidance
    c. Familiarization with flight plan
2. Advanced system familiarization
    a. Review possible alerts
    b. Review responses
3. Conventional system familiarization
    a. Review alerts
    b. Review responses

APPENDIX G

SYSTEM VALIDATION
AND
TIME-CRITICAL TEST
DEBRIEFING QUESTIONNAIRE

Observer No. 13

Name: ____________________ Date: ____________________

Phone: ____________________

Age: $\bar{X} = 46.8$

Number of years flying: $\bar{X} = 27.2$

Approximate number of flight hours: $\bar{X} = 13,600$

In the space below, identify the types of aircraft you have flown. Put a 1 above the aircraft type you have flown most recently, a 2 above the next, and so on.

8	7	4	2	6	4	2	3		
(B-707)	(B-727)	(B-737)	(B-747)	(DC-9)	(DC-10)	(L-1011)	(DC-8)	( )	( )
								Other	

DEBRIEFING QUESTIONNAIRE

OBSERVER ______________________________ DATE ________________

A. SYSTEM COMPARISON

	Advanced system	About equal	Conventional system
1. Which system provided easier problem identification?	☐ 85%	☐ 7.5%	☐ 7.5%
2. Which system was most effective in getting your attention?	☐ 92.5%	☐ 7.5%	☐
3. Which system would you prefer for the crew alerting system?	☐ 100%	☐	☐
4. Which visual system was easier to use?	☐ 92.5%	☐	☐
5. Which tone system was easier to use?	☐ 85%	☐ 7.5%	☐ 7.5%

	Tone-voice	About equal	Tone only
6. Which aural alerting mode was most effective in getting your attention?	☐ 61.5%	☐ 31%	☐ 7.5%
7. Which mode would you prefer in the cockpit?	☐ 69%	☐ 23.5%	☐ 7.5%

	Too low	About equal	Too high
8. Evaluate aural-alerts loudness with respect to aircraft noise.	☐	☐ 77%	☐ 23%

Comments:

B. ADVANCED SYSTEM COMPONENT EVALUATION

INSTRUCTIONS: FOR EACH OF THE QUESTIONS BELOW, ASSIGN A SCALE VALUE FROM 1 TO 5 BY CHECKING THE APPROPRIATE BOX.

Scale values:

1 = Unacceptable—major changes necessary
2 = Poor—major changes recommended
3 = Fair—minor changes recommended
4 = Good—minor changes beneficial
5 = Excellent—no changes recommended

	Rating 1	2	3	4	5
1. How appropriate was the location of the visual information display?	☐	☐	☐ 7.5%	☐ 77%	☐ 15.5%
2. Rate the following characteristics of the visual information display.					
a. Character size	☐	☐	☐ 15.5%	☐ 69%	☐ 15.5%
b. Color	☐	☐	☐ 15.5%	☐ 69%	☐ 15.5%
c. Brightness	☐	☐	☐ 15.5%	☐ 69%	☐ 15.5%
d. Character separation	☐	☐	☐ 31%	☐ 46%	☐ 23%
e. Message content	☐	☐	☐ 23%	☐ 54%	☐ 23%
f. Flashing box	☐	☐	☐ 15%	☐ 54%	☐ 31%
3. Evaluate the tones selected for this study.					
a. Warning	☐	☐ 7.5%	☐ 15.5%	☐ 31%	☐ 46%
b. Caution	☐	☐ 7.5%	☐ 69%	☐ 23%	☐
c. Advisory	☐	☐	☐ 23%	☐ 46%	☐ 31%

	Rating 1	2	3	4	5
4. Rate the following characteristics of the tones.					
a. Attention-getting value	☐	☐	☐	☐ 31%	☐ 69%
b. Information content	☐	☐ 7.5%	☐ 23%	☐ 54%	☐ 15%
c. Potential for disruption	☐	☐	☐ 23%	☐ 62%	☐ 15%
d. Number of tones	☐	☐ 7.5%	☐ 7.5%	☐ 54%	☐ 31%
5. Evaluate the ease of use of the voice system.	☐	☐	☐ 7.5%	☐ 54%	☐ 38%
6. Evaluate the voice component with respect to the confusion of the alerts with other communication.	☐	☐	☐	☐ 38%	☐ 62%
7. Rate the voice component on the following characteristics.					
a. Attention getting	☐	☐	☐	☐ 46%	☐ 54%
b. Intelligibility	☐	☐	☐ 15%	☐ 31%	☐ 54%
c. Message content	☐	☐ 7.5%	☐ 7.5%	☐ 23%	☐ 62%
d. Loudnesss	☐	☐	☐ 15%	☐ 38%	☐ 46%
e. Repetition rate	☐	☐ 7.5%	☐ 15%	☐ 38%	☐ 38%
f. Voice type	☐	☐	☐ 7.5%	☐ 38%	☐ 54%

Comments:

C. TIME-CRITICAL ALERTS

	Center panel	About equal	Pilots panel
1. At which location did you see the alert the fastest?		85%	15%
2. Which location do you prefer for time-critical alerts?		69%	31%

	Guidance	About equal	Status
3. Which alert format is easier for you to use?	69%	31%	
4. Which format would promote the quickest response for a time-critical alert?	54%	31%	15%
5. Which format do you prefer for the time-critical alerting system?	77%	23%	

	Graphic	Alpha	Both	No difference
6. Which type of presentation is easiest to use?		69%	31%	
7. Which type of presentation will promote the fastest response?		69%	23%	8%
8. Which type of presentation will result in the fewest errors?		54%	38%	8%
9. Which type of presentaiton do you prefer for the time-critical alerting sys\iem?		54%	46%	

Comments:

SYSTEM FEATURE IDENTIFICATION

INSTRUCTIONS: Considering all the alerting concepts that have been used during your test flight, please identify below five features of the alerting system that you liked best:

1.	**Single tone for warning, caution, and advisory**	**69%**
2.	**Voice on cautions**	**50%**
3.	**Central location for information**	**85%**
4.	**Volume of aural alerts**	**31%**
5.	**Use of voice**	**31%**
6.	**Distinct color for urgency levels**	**23%**

Five features that you liked least:

1.	**Time-critical graphics**	**54%**
2.	**Caution tone too urgent**	**38%**
3.		
4.		
5.		

Five changes that you would make (if any):

1.	**Use EADI for time-critical**	**69%**
2.		
3.		
4.		
5.		

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